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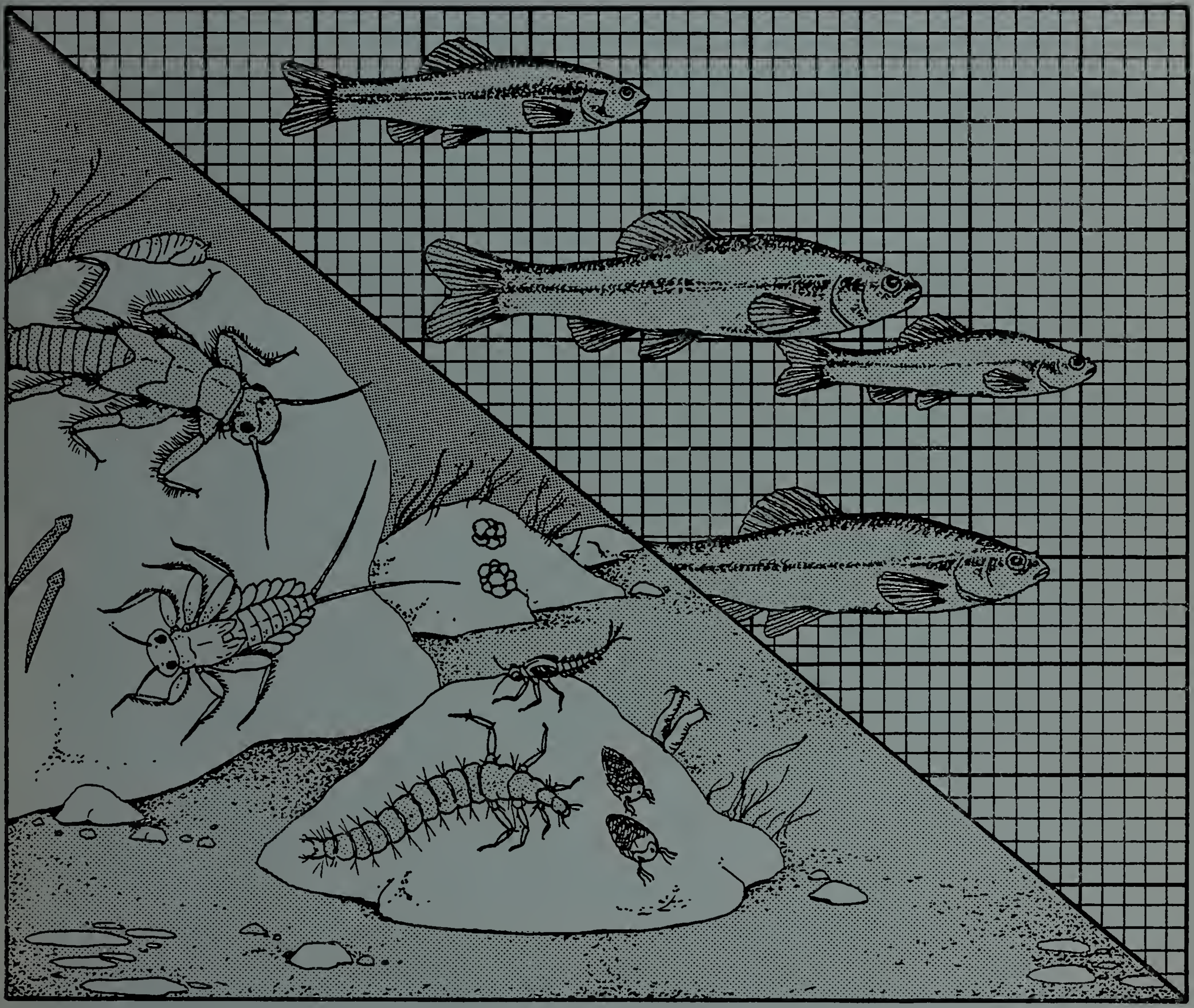
A COMPARISON OF ACUTE TOXICITY EVALUATIONS WITH MACROINVERTEBRATE COMMUNITY ANALYSES



Massachusetts Department of Environmental Quality Engineering

DIVISION of WATER POLLUTION CONTROL

Thomas C. McMahon, Director

A COMPARISON OF ACUTE TOXICITY EVALUATIONS WITH MACROINVERTEBRATE COMMUNITY ANALYSES AT SITES OF ELECTROFINISHING DISCHARGES TO STREAMS IN MASSACHUSETTS

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EXECUTIVE SUMMARY

Purpose and Approach

This research was conducted to evaluate the effectiveness of three static acute toxicity tests in assessing the potential toxicity of electrofinishing wastes discharged to streams.

The following tests were evaluated:

1) the fathead minnow (Pimephales promelas) 48-hour test;

2) the Microtox (Beckman Instruments, Inc.) 30-minute test; and

3) the Daphnia pulex or D. magna 48-hour test.

Four sites of electrofinishing wastewater discharges to streams in Massachusetts were selected for study. Benthic macroinvertebrate community evaluations were conducted at stations located both upstream and downstream of each wastewater discharge. The results of these studies were assumed to be true measures of impact due to the discharge of effluents at each site.

Composite effluent samples were collected at each of the facilities chosen for study. Three acute toxicity tests as well as chemical evaluations were conducted on these effluents. The results of these tests were used to calculate a predicted instream toxicity at each of the study sites. Predictions were then compared to impacts that were observed through benthic community evaluations.

Application factors and their effect on predicted instream toxicity were also assessed.

Procedures

Selection of the electrofinishing facilities evaluated in this study was based on a) the consistency in both flow and quality of effluent discharge (this simplified dilution calculations); and b) the nature of the stream receiving the discharge (a control and a test site were needed to make an assessment of impacts).

Benthic macroinvertebrate community evaluations were conducted at each site by Division of Water Pollution Control Technical Services Branch personnel. Surber samplers were used to collect invertebrates in riffle areas at stations upstream and downstream of each effluent discharge. Organisms collected in these samples were keyed out to lowest possible taxonomic category and archived. Indices of community structure (Shannon Weaver H', Simpson's D, evenness and richness) were used to determine if impacts due to the effects of the discharge had occurred at the site under investigation. Two of these studies were conducted on separate dates at each site between July and September of 1982.

Composite samples (24-48 hr.) of wastewater effluents were collected at each of the four sites by automatic samplers. Each sample was mixed and representative subsamples were separated for acute toxicity testing and chemical analysis.

Acute toxicity analyses were conducted by three laboratories. The Biology Section of the Region I U.S. Environmental Protection Agency (EPA) laboratory in Lexington, MA conducted all but one of the Daphnia sp. and fathead minnow tests; the Civil Engineering Department at the University of Massachusetts in Amherst, MA conducted one set of all three toxicity tests; and the DWPC Technical Services Branch conducted Microtox evaluations on all but one of the samples. Methods used in Daphnia sp. and fathead minnow tests were those outlined by Peltier (1978). Microtox evaluations were conducted according to the methods recommended by the manufacturer (Beckman Instruments, Inc., 1982).

Chemical analyses were conducted by the Massachusetts Department of Environmental Quality Engineering (DEQE) Lawrence Experiment Station in Lawrence, MA. EPA Standard Methods (EPA, 1979) were used for these analyses.

For each of the sites back calculations were made to estimate instream toxic effects on dates of macroinvertebrate community evaluations. Two sets of calculations were made for each site: one based on results of acute toxicity tests, and one based on the results of chemical evaluations. In each set of calculations, instream dilutions of wastewaters were estimated according to a) stream flow measurements at time of macroinvertebrate community evaluations; and b) wastewater flows averaged over times of discharge for a two-week period prior to macroinvertebrate sampling dates at each site.

It should be noted that the collection of effluent samples did not necessarily coincide with dates of macroinvertebrate sampling. In order to make back calculations of instream toxicity over periods immediately prior to macroinvertebrate evaluations it was necessary to assume that effluent toxicity was fairly constant over the duration of the study. Additional effluent testing was conducted as a check on this assumption.

The following relationship was used in making back calculations of predicted toxicity based on acute toxicity tests (taken from Malina, 1984):

$Q_s = DV(Fd)$ where Q_s = the stream flow necessary to dilute effluent sufficiently so as not to have a toxic effect

DV = dilution volume

$$= \frac{100 - LC_{50}\ (\%)}{LC_{50}\ (\%)}\ Qe$$

Qe = wastewater flow

Fd = reciprocal of application factor.

Values of Qs were compared to stream flows (Qr) at dates of macroinvertebrate community investigations. If Qs exceeded Qr, instream toxic effects were predicted. If Qr exceeded Qs, instream toxic effects was not predicted.

The relationship below was used to make predictions of instream toxic effects based on the results of chemical analyses:

$$T = \sum_{i=1}^{X} \frac{Qe \cdot Ci/(Qe + Qr)}{Wi}$$

where T = Toxic Units of a particular effluent sample

Ci = concentration of chemical i found in sample

X = the number of chemical components being evaluated

Wi = EPA Ambient Water Quality Criterion (EPA, 1980) for component i

Qe = flow of wastewater discharge

Qr = flow of receiving water

Toxic effects of chemical components of an effluent were considered to be additive: a value of $T > 1.0$ would therefore yield a prediction of instream toxic effects.

Projections of instream toxicity based on these calculations were compared to results of macroinvertebrate community analyses to evaluate the effectiveness of each test in predicting community changes.

Results

Daphnia sp. acute toxicity tests were the most effective of the three tests in predicting impacts to macroinvertebrate communities.

Predictions of instream toxicity based on the results of these tests matched the results of the macroinvertebrate community evaluations in all cases. In addition, the Daphnia sp. tests were consistently the most sensitive of the three acute toxicity analyses conducted. In one of the four cases where impacts to macroinvertebrates were observed, an application factor of 0.1 was needed to accurately predict instream toxic effects. In the other three cases, no application factor was needed.

The Microtox 30-min. test was successful in predicting observed impacts in all but one of the four situations where impacts were observed. This test was not as sensitive as the Daphnia sp. tests to the effluents evaluated in this study but concurred with the latter regarding whether or not an effluent was toxic. An application factor of 0.1 was needed to successfully predict instream toxic effects in two cases where impacts were observed.

The fathead minnow test failed to predict instream toxicity in any of the situations where impacts were observed through macroinvertebrate analyses.

At the two sites where no impacts to macroinvertebrates were observed, predictions based on the results of all three acute tests matched the observations in all cases.

Chemical assessments successfully predicted impacts when the latter were observed through aquatic community studies. However, these assessments also predicted instream toxic effects at one site when no impacts were observed.

There was a negative correlation between predictions of instream toxicity and degree of actual impact at the two sites where impacts were observed. This anomaly may be due to the fact that the duration of each discharge was not factored into the equations used to predict instream toxicity. At the site where greater impacts were observed, discharge duration (daily) was 20 hours; at the other site where impacts observed were not as severe, discharge duration was only eight hours. Ultimate toxicity is often a factor of both toxicant concentration and duration of exposure. As a result, a 16-hour interval between discharges at the latter site may have the effect of providing a recovery period for the organisms exposed to the effluent. Thus, impacts to the exposed community would be less than those encountered if the duration of the discharge were extended.

Summary of Findings

- the Daphnia sp. (pulex and magna) 48-hour static acute test was the most accurate predictor of instream toxicity of the three toxicity tests conducted in this study;

- the Microtox test was a good predictor of instream toxicity but was not as sensitive as the Daphnia tests;

- the fathead minnow test was not an accurate predictor of instream toxicity;
- EPA Ambient Water Quality Criteria (EPA, 1980) were good predictors of instream toxic effects where they were observed but also predicted toxic effects in one case where impacts were not observed;
- an application factor of 0.1 was needed to successfully estimate instream toxic effects in certain cases;
- effluent toxicity is often a factor of both toxicant strength and time of exposure. Discharge duration, therefore, should be taken into account when the results of toxicity tests are used in developing guidelines for permit evaluations.

ACKNOWLEDGMENTS

Michael Bilger and Peter Nolan of the Biology Section at the United States Environmental Protection Agency, New England Regional Laboratory in Lexington, Massachusetts, ran most of the acute toxicity tests for this study. Michael Bilger also identified certain problem invertebrate taxa and confirmed other identifications.

Dr. Neil Ram, and several of his graduate students at the University of Massachusetts Department of Civil Engineering in Amherst, Massachusetts, conducted toxicity tests for one of the samples under contract no. 80-32 to the Division of Water Pollution Control.

Dr. Anthony Bulich of the Beckman Instruments Corporation in Carlsbad, California, graciously provided the Division with a Microtox unit for the duration of the research.

Chemical analyses were conducted by the Water Chemistry and Wastewater Laboratories at the Lawrence Experiment Station, Division of Laboratories, Lawrence, Massachusetts.

Members of the Division of Water Pollution Control, Technical Services Branch, assisted in macroinvertebrate collection and identification, computer analysis, and in the review and revision of this report. Figures were done by Barbara J. Kimball and typing by Aline L. Charest also of the Technical Services Branch.

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PURPOSE

This research was conducted to assess the utility of three static acute toxicity tests in evaluating the effects of electrofinishing waste discharges to streams in Massachusetts.

These tests include the following:

1) the fathead minnow (Pimephales promelas) 48-hour test;

2) the Microtox (Beckman Instruments, Inc.) 30 min. test; and

3) the Daphnia pulex or D. magna 48-hour test.

Each of these tests was conducted on wastewater effluents collected from four electrofinishing plants with discharges to streams in Massachusetts. Predictions of instream toxicity based on the results of these tests were compared to impacts observed through macroinvertebrate community analyses conducted at each site. Application factors and their effect on predicted toxicity were also assessed.

BACKGROUND

Aquatic toxicity tests are quickly becoming an integral aspect of federal and state water pollution assessment programs. Federal authorization for the use of these tests in the evaluation of permitted effluent discharges was established in the Federal Water Pollution Control Act, Amendments of 1972 (PL 92-500) and the 1977 Amendments. In 1978, the Federal Environmental Protection Agency (EPA) published a standardized methods manual for conducting these tests (Peltier, 1978) and a revised edition of this text is expected to be released later this year.

The Commonwealth of Massachusetts also recognizes the utility of these tests in the analysis of wastewaters. The Water Quality Standards (314 CMR 4.03) of the Massachusetts Division of Water Pollution Control (DWPC) sanctions the use of aquatic toxicity tests in NPDES permit evaluations. A standard format to be used by consultants in conducting and reporting these tests is currently being developed by DWPC. In addition, DWPC is investigating the potential for developing in-house capabilities for conducting these tests.

Toxicity tests assess the potential that a substance, or combination of substances, may have of adversely affecting the life process. They are often structured to measure the effects of a range of toxicant concentrations to a single species population of organisms over a specific unit of time.

There are two basic types of toxicity tests: acute and chronic. The former are short-term tests and usually encompass only a portion of the test organism's life cycle. When the measured effect is mortality, results are expressed as the percent toxicant lethal to fifty percent of the organisms tested (i.e., the LC_{50}). When effects other than mortality are measured, such as the change in rate of certain physiological or behavioral processes, results may be reported as the percent toxicant causing a fifty percent reduction of the measured effect (i.e., the EC_{50}).

Chronic tests are long term tests. Test duration usually encompasses at least one, and usually more than one, generation of the organisms tested. An array of non-lethal effects of toxicants, such as decreased fecundity, reduction in growth rates or increase in tumor formation, can be evaluated in these tests. Results are expressed as a "no effect level", i.e., the highest concentration of toxicant where measured effects to exposed organisms are not significantly different from those measured in the control (non-exposed) group.

Toxicant concentrations inducing chronic alterations may be orders of magnitude lower than those causing acute effects. For this reason when acute tests are used to set effluent limits for a particular discharge, LC_{50}'s derived from these tests are usually multiplied by an "application factor" of from 0.5 to 0.001 to protect organisms from chronic effects. Although chronic tests provide a more precise estimate of "safe" instream levels of toxicants than acute tests, the latter are most often chosen for use by regulatory agencies in effluent testing. The reason for this is primarily economic: acute tests are much less expensive than chronic tests.

The alternatives to toxicity tests most commonly employed in assessments of effluent toxicity are chemical evaluations and instream aquatic community studies. The first is a comparison of toxic components of the effluent to criteria established for those components. While the results of these analyses provide the regulator with an easily interpreted data set, this chemical components approach to toxicity evaluation has a number of shortcomings when compared with the live organism approach:

a) effluent criteria have not been established for many chemicals so estimates of instream toxicity based on chemical analyses may, therefore, be somewhat tenuous;

b) synergistic and/or antagonistic reactions of a complex waste are accounted for in the live organism test but not in chemical analyses;

c) site specificity of receiving waters can be incorporated into the toxicity test by using site waters as diluants. Hardness, pH, and other local conditions that affect toxicity are thereby included; and

d) chemical analyses rely on the previous identification of potentially toxic components; in contrast, toxicity tests take a "black box" approach and the analyst need not know the suspected toxicants beforehand.

In addition to the above, aquatic toxicity tests can be less expensive than sophisticated chemical analyses of complex wastes.

The second alternative to toxicity testing is the instream aquatic community evaluation. It differs from toxicity testing and chemical testing in that the latter methods are predictive and speculative while community evaluations are used to establish whether or not impacts have already occurred. If community evaluations are properly conducted, differences in community structure at the "test" site are measures of the impact of the discharge.

While often useful in pollution evaluations, aquatic community analyses have at least two noteworthy flaws:

a) they can be extremely labor intensive and often require expertise that is not readily available; and

b) in those cases where a number of point discharges are found in close proximity to one another, instream community analyses may be inappropriate for the evaluation of any one of those discharges. For example, if the impact evaluation of one of these discharges is based on comparisons of aquatic communities above and below the discharge, results of these studies will be muddled due to the potential of encountering pollution-stressed organisms in the upstream (control) study area.

In comparison to these analyses, acute toxicity tests are significantly less labor intensive and the methodology of testing and reporting can be readily learned. Furthermore, toxicity tests can be used to evaluate the toxicity of individual waste discharges to the same water body. A method of assessing the cumulative effects of multiple discharges through the use of toxicity tests, however, has yet to be developed.

Other flaws of toxicity tests when they are used in effluent evaluations include the following:

a) species of aquatic organisms vary in their sensitivity to a particular toxicant, often over orders of magnitude. As a result, determinations of a "safe" instream concentration will vary with the organism and even the life stage used in the test;

b) mortality, the measured effect in most acute tests, cannot be used by itself to establish a "safe" level of exposure instream. Toxicant concentrations producing chronic effects cannot be accurately predicted from acute tests and judgments concerning the choice of an application factor may therefore be subjective.

In light of the above, regulatory agencies using acute toxicity tests are faced with two questions:

1) how to choose the most appropriate toxicity test for a particular effluent; and

2) how application factors should be used to protect aquatic communities from chronic effects in waters receiving effluent discharges.

STUDY DESIGN

One method of research that may be of assistance to regulators in addressing these questions is the following: a) categorize industrial facilities into different classes based on the chemical components of their discharge; b) determine which, if any, toxicity tests are consistent in their sensitivity to an array of effluents in a particular class; and c) determine if predictions of instream toxicity from these tests have a positive correlation with results of aquatic community analyses at sites exposed to the effluent class in question.

The research presented here followed the approach outlined above in a small scale investigation of electrofinishing waste discharges to streams in Massachusetts. Benthic macroinvertebrate community assessments were conducted in receiving waters subject to wastewater discharges from several electofinishing plants. Results of these analyses were compared to projections of impact based on three static acute effluent toxicity tests: the fathead minnow 48-hour test, the Microtox (Beckman Instruments) 30-minute test, and either the _Daphnia pulex_ or _D. magna_ 48-hour test depending on the site.

Effluent samples were collected from four electrofinishing facilities between the months of July and December, 1982. One representative sample was taken at each site. Each sample was mixed and split for acute toxicity tests and chemical analysis. Each of the three toxicity tests described above was conducted on these effluents. Chemical analyses were conducted for parameters selected from the NPDES permit for each facility.

At each of the four sites benthic macroinvertebrate community sampling was conducted on two separate occasions between the months of July and September of 1982. Coincident with each sampling event, three Surber samples were taken upstream and three downstream of the effluent discharge in areas of similar physical habitats. Facilities were selected that exhibited a low solids component to their discharge so that alterations in macroinvertebrate community structure due to toxicants would not be confused with those due to habitat alterations from settleable solids. Sites were located such that interfering sources of pollution upstream from both sampling stations were minimal.

The following additional data were collected on dates of macroinvertebrate sampling: instream flow; wastewater flow (from wastewater treatment operators); and instream water quality.

Macroinvertebrate samples from individual sampling events were analyzed as follows: a) invertebrates from each 3-sample collection (one upstream and one downstream) were keyed out to lowest possible taxonomic order and recorded; b) these data were combined into one data set; c) calculations of taxonomic richness, Model-free evenness (Williams, 1977) and two measures of diversity were made for each data set; d) determinations of impact/no impact were made after comparing community indices and raw data from upstream and downstream sample collections at each site. These determinations were considered to be measures of impact due to electrofinishing waste discharges at each site.

Predictions of instream toxicity were made for each site using the results of acute toxicity tests and chemical analyses of representative effluent samples collected at each facility. Dilution calculations used for these predictions were based on: (a) instream flows at dates of macroinvertebrate collections; and (b) wastewater flows averaged over periods of discharge for two weeks prior to (a). It should be noted here that effluent sample collections were not necessarily coincident with macroinvertebrate collections.

Predictions of instream toxicity were then compared with determinations of impact from the macroinvertebrate community evaluations.

Assumptions basic to these comparisons are (1) wastewater flows are uniform (in order that dilution calculations accurately predict instream effluent concentrations); and (2) effluent samples analyzed are representative of wastes discharged to receiving streams prior to dates of macroinvertebrate collection dates (i.e., effluent toxicity was fairly uniform over the course of the study).

In order that these assumptions be met, sites were chosen which had (a) a constant and/or predictable discharge over daily periods of operation; and (b) as consistent as possible a mode of operation and treatment. Although certain sites chosen for this study did not meet criterion (b) as well as others, they did represent the best sites practically available. Final selection of four sites was based in a pre-screened list of 29 possible facilities compiled by the Division's Permit Section and site visits to 24 of these facilities.

SITE DESCRIPTIONS

General

Electrofinishing effluents are common discharges to Massachusetts streams. The electrofinishing process usually includes stripping, removal of oxides, cleaning and plating of pre-formed metals. Discharges are small in volume but may contain potentially toxic substances such as cyanides, acids, alkalis, chromates and other metals. Soaps, grease, oil and suspended solids are also typical components. The nature of the operations (batch processes, varying rinse cycles) often results in erratic discharge patterns. Each of the effluents reported in this study has permit limits based on best available treatment prior to discharge.

Whiting and Davis, Inc.

Whiting and Davis, Inc. is located in Plainville, in southeastern Massachusetts near the Rhode Island border (see Figure 1A). It has an electrofinishing operation with wastewater that is ultimately discharged to the Ten Mile River. Immediately prior to discharge is a settling tank with 20-30 minute retention time. Over the course of these investigations this effluent was flowing continuously on an 8 to 9-hour per day, 5-day per week schedule.

At this location, the Ten Mile River is a first order stream with an 8.5 square kilometer drainage area (see Table 1 for a summary of stream and effluent discharge information for all sites). The river's headwaters are located approximately three kilometers upstream in a wetland. From this point the stream flows southward, losing only 12 meters in elevation in three kilometers as it travels through a set of small ponds and wetlands. The banks of the stream have been "improved" by horizontal stacking of railroad timbers to a height of about 1.5 meters in the vicinity of the Whiting & Davis discharge.

Sampling stations were located in this channelized stretch of water (see Table 2 for a list of habitat characteristics for all sites). The upstream site was approximately 25 meters above the discharge and the downstream site was about 50 meters below the discharge. The substrate in both areas was sand overlain by gravel and cobble. Overhanging riparian vegetation was minimal at these locations and shading was restricted to that afforded by the high banks. River width was 2.5 meters at both locations. Water depth ranged from 0.3-0.4 meters at the first sampling in July, and 0.1-0.2 meters at the second sampling in September.

A parking lot for Whiting & Davis, Inc. employees was located adjacent to the plant. During rain events runoff from this lot entered the stream at a point approximately 30 meters above the upstream sampling site. A town storm drain located approximately 0.5 kilometers above the upstream sampling station was another potential source of pollution.

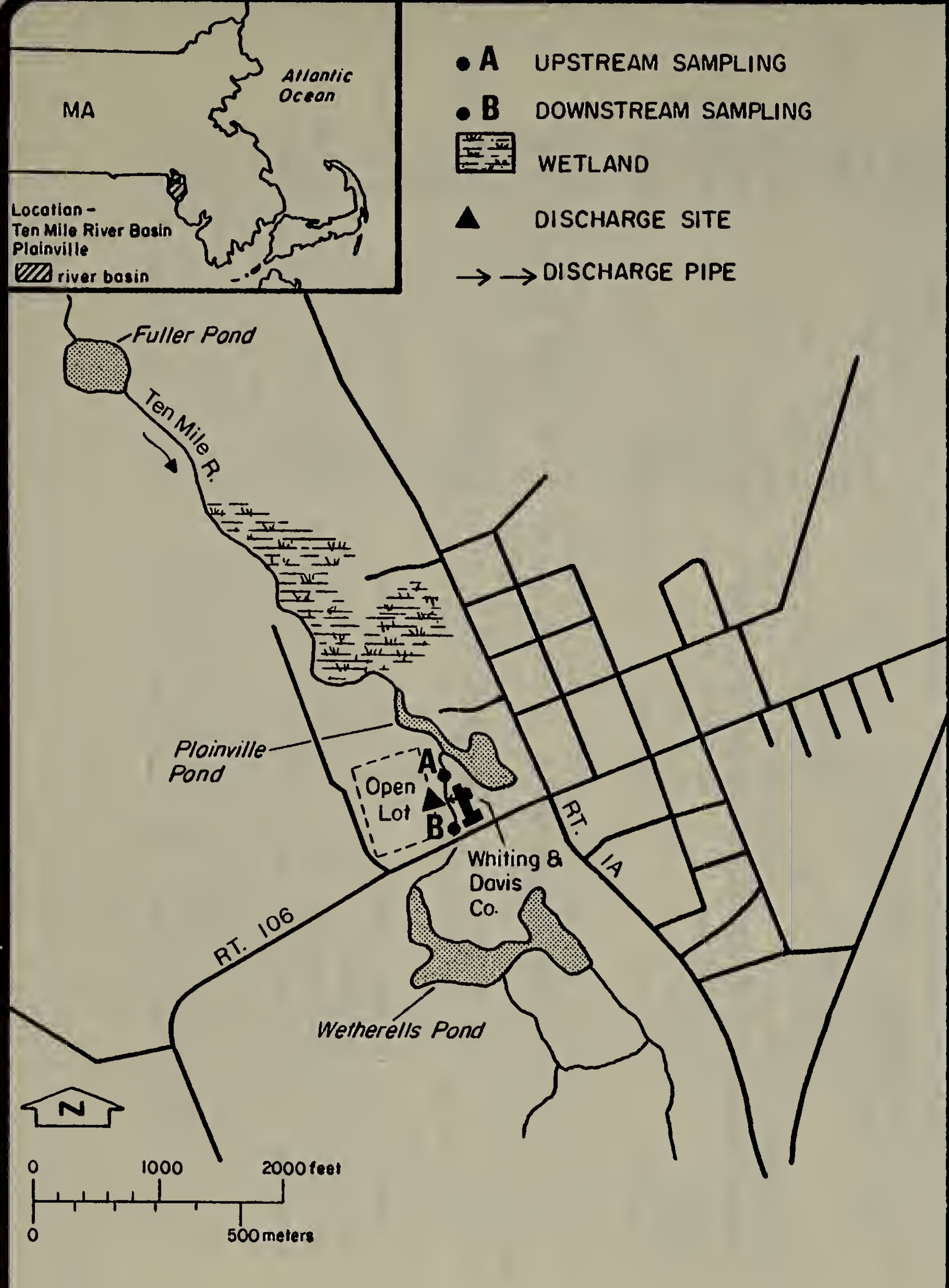

Figure 1A - SITE MAP: WHITING & DAVIS, INCORPORATED

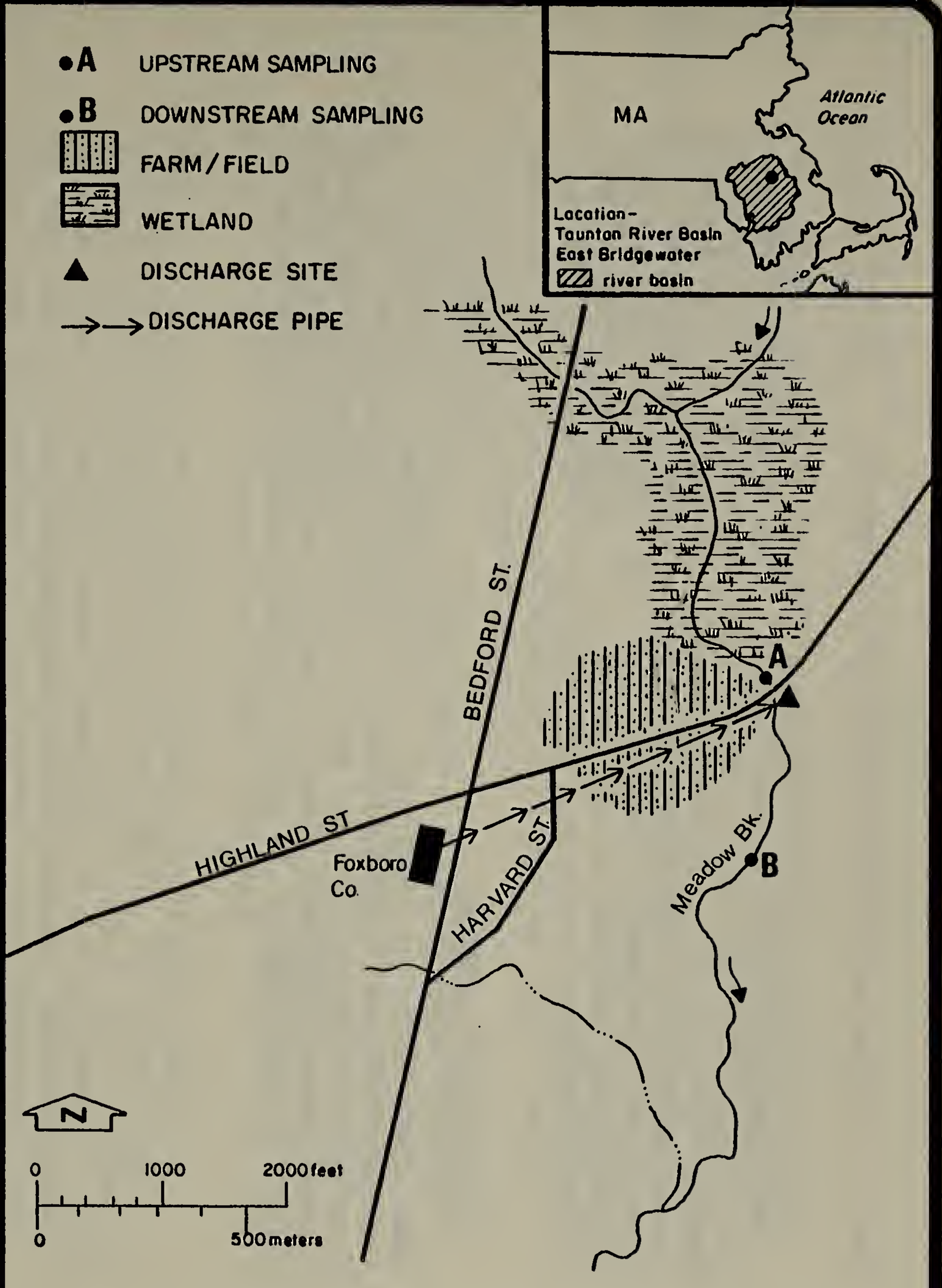

Figure 1B - SITE MAP: FOXBORO COMPANY

Table 1. Stream and effluent discharge information.

Whiting & Davis Inc.

Town: Plainville
Average Plant Flow: 152 m^3/day
River: Ten Mile River
Drainage Area: 8.5 km^2
7Q10: 807 m^3/day

Foxboro Company

Town: East Bridgewater
Average Plant Flow: 284 m^3/day
River: Meadow Brook
Drainage Area: 10 km^2
7Q10: 763 m^3/day

Columbia Mfg. Company

Town: Westfield
Average Plant Flow: 2,725 m^3/day
River: Little River
Drainage Area: 218 km^2
7Q10: 32,775 m^3/day

Zero Corporation

Town: South Monson
Average Plant Flow: 151 m^3/day
River: Chicopee Brook
Drainage Area: 40 km^2
7Q10: 3,900 m^3/day

Table 2. Benthic sampling habitat characteristics.

	Whiting & Davis Inc.		Foxboro Company	
	Upstream	Downstream	Upstream	Downstream
Distance:	25 m	50 m	8 m	300 m
Substrate:	gravel/cobble	gravel/cobble	cobble	cobble
Depth:	0.1-0.4 m	0.1-0.4 m	0.2-0.4	0.3-0.4 m
Width:	2.5 m	2.5 m	2.1-3.4 m	2.1-3.8 m
Shading:	minimal	minimal	70%	90%

	Columbia Mfg. Company		Zero Corporation	
	Upstream	Downstream	Upstream	Downstream
Distance:	800m	200 m	15 m	90 m
Substrate:	gravel/cobble	gravel/cobble	gravel/cobble	gravel/cobble
Depth:	0.2-0.3	0.25-0.3	0.3	0.3
Width:	12-14 m	12-14 m	4.3-4.7	6.1-6.7
Shading:	minimal	25%	70%	50%

Foxboro Company

The Foxboro Company is located in southeastern Massachusetts in East Bridgewater (see Figure 1B). It discharges both municipal waste and electrofinishing wastewater to an 0.9 kilometer pipeline emptying into Meadow Brook, a tributary to the Taunton River. During this study the municipal component of the effluent averaged slightly less than one third of the total discharge. This portion of the waste is treated by a series of septic tanks, sand filters and chlorination before it is mixed with the industrial component and discharged to the pipeline. The plant was discharging effluent on a 24-hour per day, 6-day per week schedule during the evaluation.

At the point of discharge, Meadow Brook is a second order stream with a 10 square kilometer drainage area. The headwaters of the brook are located in the town of Whitman, a fairly industrialized area, and to the west of Whitman in a wetland. From these two areas, the upper branches of the brook flow southward primarily through wetlands. In the vicinity of the Foxboro Company discharge, Meadow Brook is a slow moving stream with fine-grained organic substrates.

Sampling stations were located at stream constrictions, where increased velocities scoured moss-covered cobble substrates. The upstream sampling station was located 8 meters above the discharge and the downstream station 300 meters downstream of the discharge. During the two sampling dates stream widths varied from 2.1 to 3.4 meters at the upstream site and from 2.1 to 3.8 meters at the downstream site. Depths ranged from 0.2 to 0.4 meters upstream and from 0.3 to 0.4 downstream. Deciduous overhanging canopies provided approximately 70% shading at the upstream site and 90% shading at the downstream site.

Just above the upstream sampling site the brook is abutted by a farmer's field for approximately 0.5 kilometers. This is a possible source of nutrients, pesticides and farm animal wastes during rain events.

Columbia Manufacturing Company

Columbia Manufacturing Company (see Figure 1C) has an electrofinishing operation in Westfield, Massachusetts. Its wastewater is discharged to the Little River, a tributary of the Westfield River. The discharge is carried by a pipeline for 0.5 kilometers and then enters a drainage ditch bordering a farmer's field for 200 meters before it enters the Little River.

The Little River is the largest of four streams studied. It is a fifth order stream with a drainage area of 218 square kilometers. The substrate varies from cobble/rock, sand and mud and there are some deep pools (>2 meters). The upstream sampling station was located 0.8 kilometers upstream of the drainage ditch confluence in a riffle area with a cobble substrate. Stream width varied from 13 to 15 meters and depths from 0.2 to just over 0.3 meters. The downstream station was

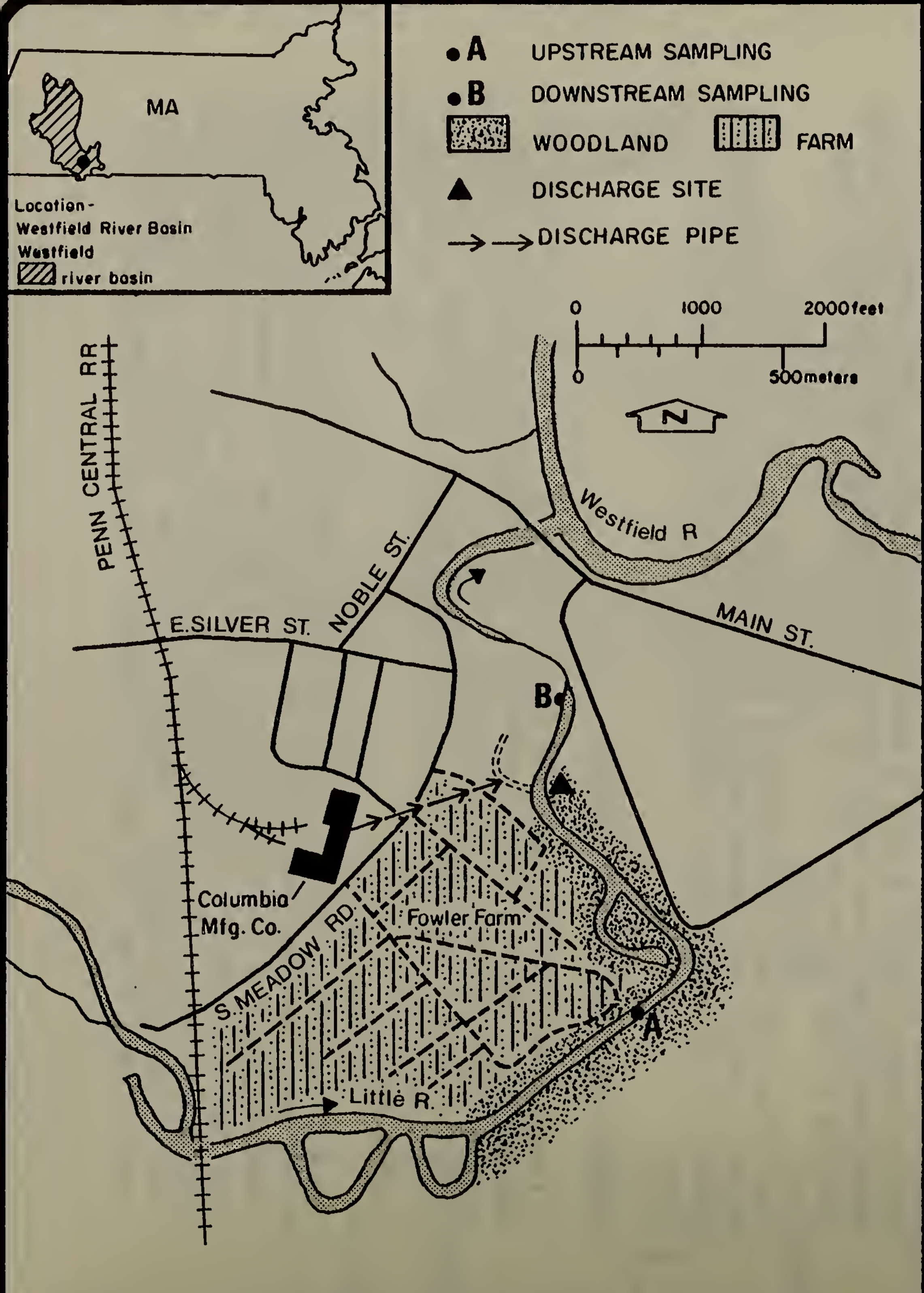

Figure 1C - SITE MAP: COLUMBIA MANUFACTURING COMPANY

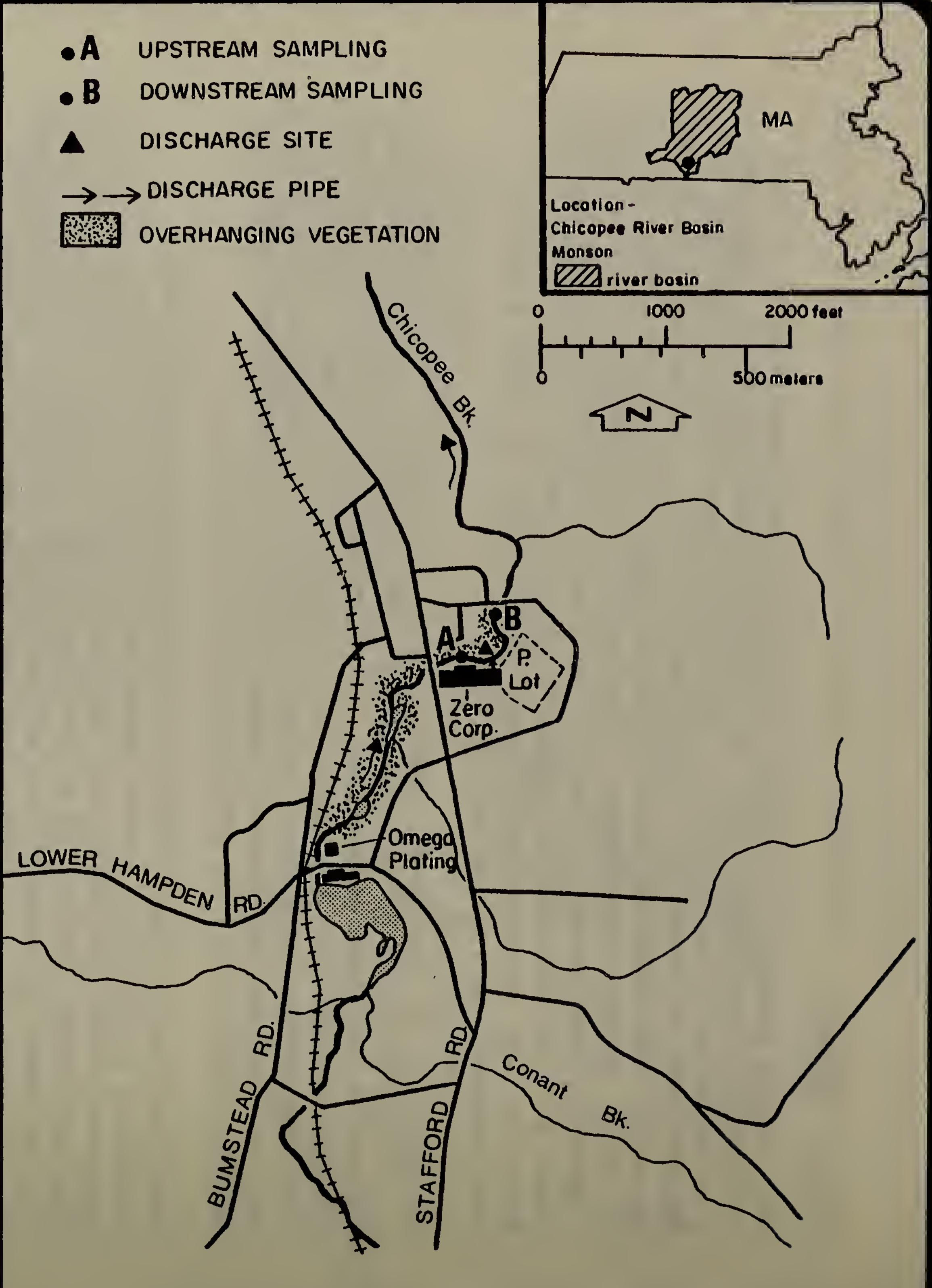

Figure 1D - SITE MAP: ZERO CORPORATION

also located in a riffle area with cobble substrate 0.2 kilometers below the discharge. Widths between 12 and 14 meters and depths of 0.25 to 0.30 meters were recorded during the surveys. Shading was minimal at the upstream station and 25% at the downstream station.

Farm fields border the upstream site and continue for 0.4 kilometers below the site. It is known that pesticides are applied to this field (Thiodan and Dipel) and are a potential source of toxic pollution during rainfall events. No other interfering sources were identified.

Zero Corporation

Zero Corporation (see Figure 1D) is located in south-central Massachusetts, in South Monson. Wastewater from the electrofinishing operation is discharged to Chicopee Brook. At the time of these investigations, Zero had a 20-hour per day, 4-day per week discharge.

At the point of discharge, Chicopee Brook is a third order stream of approximately 40 square kilometer drainage area. The brook flows north from headwaters located about 9 kilometers south of the discharge. Chicopee Brook and its feeder streams flow through a series of small mountain ponds and wetland areas dropping 180 meters in elevation to South Monson. The Massachusetts Division of Fisheries and Wildlife stocks these streams with trout.

Sampling stations were located in riffle areas with cobble/gravel substrates 15 meters upstream and 90 meters downstream of the discharge. Stream width varied from 4.3 to 4.7 meters at the upstream site. At the downstream site widths varied from 6.1 to 6.7 meters. Depths at both sites were approximately 0.3 meters. Deciduous trees on the stream banks provided 70% shading at the upstream site at 50% at the downstream site.

Another electrofinishing operation discharges its wastewater 0.8 kilometers upstream of the Zero Corporation discharge. It is a small 4-5 person operation, with a 3 to 5 days per week, 8-hour per day schedule.

MATERIALS AND METHODS

Macroinvertebrates

Benthic macroinvertebrate samples were collected between June and September of 1982 at four sites of electrofinishing discharges to streams. Sampling was conducted on two occasions at each site.

Two sample stations were located at each site: one upstream of the discharge and one downstream of the zone of effluent mixing with the receiving stream. The zone of mixing was determined by visual observations of rhodomine dye added to each discharge. Upstream stations were not more than 0.6 km upstream of the point of effluent discharge. Downstream stations were at least 30 meters but not more than 300 meters downstream of the zone of effluent mixing. Samples were taken in riffle sections of similar bottom type, current velocity and degree of shading to control for macrohabitat differences between upstream and downstream stations.

At each of these sampling stations, three, 0.305 meter square Surber samples of one minute sampling duration were taken. After each bottom sample was collected, the sampling apparatus was picked clean of organisms and the sample transferred to 75% ethanol if its primary composition was invertebrates. If a large amount of debris was also present - necessitating further sorting - the sample was preserved in 5% formalin, refrigerated and sorted by hand in the laboratory.

Chironomid larvae, if present in large numbers (>150), were subsampled as follows: all chironomid larvae present in the sample were spread evenly over a petri dish that had been marked into quarter sections. Individuals in successive quarter sections were then removed until the subsample contained at least 100 organisms.

With the exception of annelids and chironomids, all other organisms in the sample were identified with the aid of a Bausch and Lomb stereomicroscope with 15-105X magnification to lowest possible taxonomic category (usually genus) and archived. Annelids were mounted on slides in Amman's medium and identified under a Swift compound microscope with 40-1000X magnification. Chironomid larvae were cleared in warm potassium hydroxide (10-15%), transferred to water and mounted on glass slides in CMC-10 mounting medium. Chironomid identifications were also made with the aid of the compound microscope.

The following keys were used for macroinvertebrate identifications: general - Pennak (1978); leeches - Klemm (1982); Oligochaeta - Hiltunen and Klemm (1980), Stimpson, Klemm and Hiltunen (1982), and Brinkhurst and Jamieson (1971); crustaceans - Williams (1972) and Holsinger (1972); aquatic insects - Merritt and Cummins (1978); Ephemeroptera - Edmunds, Jensen, and Burner (1976); Odonata - Walker (1953), and Walker and Corbet (1975); Trichoptera - Wiggins (1977); Coleoptera - Dillon and Dillon (1972, Vols. I and II);

Diptera/Chironomidae - Simpson and Bode (1980) and Bode (1983); Diptera/Simuliidae - Stone (1964); Gastropoda - Jokinen (1983); Pelecypoda - Burch (1972).

Macroinvertebrate data were analyzed as follows: data from each 3-sample collection (one such collection from each site and date upstream of the point discharge and one downstream) were consolidated into one data set and comparisons made between upstream and downstream areas for each site and date. Differences between macroinvertebrate communities above and below each effluent discharge were evaluated through an analysis of taxonomic richness, Shannon-Weaver diversity (Poole, 1974), model-free evenness (Williams, 1977) and Simpson's diversity (Poole, 1974). Qualitative methods were also used to evaluate community differences. Appendix 2 should be consulted for a description of these analytical methods.

Water Quality and Instream Flow Determinations

At each of the macroinvertebrate collection stations dissolved oxygen (D.O.), temperature and pH were measured. D.O. samples were collected according to methods outlined by Welch (1948). Determinations of D.O. were made in the laboratory using the azide modification of the Winkler idiometric titration technique (APHA, 1975). Water temperature was measured with a Taylor model T2211-4 dial thermometer. A Hach, model 17-N wide-range pH test kit was used to measure pH.

In-stream flow determinations were made at the upstream macroinvertebrate sampling station at each site. Stream velocity was measured at approximately mid-depth at intervals along a transect across each stream. A Gurley model 625 (Pygmy) current meter was used to measure current velocity. The formula $Q = V \cdot A$, where Q = in-stream flow, V = velocity and A = cross sectional area of stream, was used to estimate flow.

Dates of water quality determinations and in-stream flow measurements were coincident with macroinvertebrate collection dates.

Sampling and Chemical Analysis of Wastewater

Two sets of effluent samples were collected for toxicity testing and chemical analysis. The first set (samples A-D listed below) consisted of samples composited by automatic samplers either continuously or once every half hour over the course of at least one complete daily cycle of operation. They are referred to as "composite effluent samples" throughout the remainder of this report.

The results of analyses on this set of samples were used in all calculations of in-stream toxicity (i.e. Qs, and T from equations 1 and 2 below).

These samples were collected as follows:

Whiting & Davis, Inc. (sample A): 8-hour continuous composite sample taken near point of discharge to receiving stream on December 8, 1982;

Foxboro Company (sample B): 24-hour composite sample taken at 1/2-hour intervals at point of effluent discharge to receiving stream on November 10, 1982;

Columbia Mfg. Company (sample C): 48-hour composite sample taken at 1/2-hour intervals at point of discharge to drainage ditch on November 4, 1982;

Zero Corporation (sample D): 24-hour continuous composite taken at point of effluent discharge to receiving stream on July 27, 1982.

The above samples were taken during the middle of a weekly cycle at each plant so that these collections would be characteristic of one week's total effluent.

Other samples (E-H) were also taken at these facilities and were analyzed to elucidate certain aspects of the treatment schemes at the first three plants. None of these was used in predictions of instream toxicity. These samples were collected as follows:

Whiting & Davis, Inc. (sample E): 8-hour continuous sample taken at input to final settling tank on September 8, 1982;

Foxboro Company (sample F): grab sample of combined industrial plating discharge and domestic waste taken at end of pipe;

Foxboro Company (sample G): 24-hour continuous composite sample of final industrial effluent prior to mixing with municipal component effluent on July 14, 1982;

Columbia Mfg. Company (sample H): 6-hour continuous composite taken at point of final effluent contact with discharge pipe on August 3, 1982;

This latter set of samples are referred to as "additional effluent samples" throughout the remainder of this report.

An ISCO$^{(tm)}$ sampler with a 19-liter, acid-washed glass liner, was used to collect samples composited on a half-hour basis. DWPC personnel conducted this sampling. Samples composited on a continuous basis were collected by EPA personnel. A small pump which conducted the sample to a pre-washed Nalgene container was used for these collections. The grab sample was also collected by EPA via a pre-washed plastic bucket.

Approximately 19 liters of effluent were collected for toxicity testing during each sampling event. After collection was completed the samples were put on ice and taken to the laboratory. Once in the laboratory each sample was mixed by repeated transfer between containers. One, 2-liter aliquot of this mixed sample was separated for chemical evaluations. A smaller aliquot was separated for Microtox analysis and the rest of the sample was used for Daphnia and fathead minnow toxicity tests.

Chemical samples were packed in ice and delivered to the Lawrence Experiment Station, Massachusetts Department of Environmental Quality Engineering where they were analyzed. Techniques used at the Lawrence Experiment Station followed EPA (1979) protocols as follows: cadmium, copper, lead, nickel, silver and zinc determinations were made by atomic absorption spectrophotometry with an air-acetylene flame (Perkin-Elmer Model 403). Hexavalent chromium determinations were made using the diphenyl-carbozide colorimetric method (Klett-Summerson photoelectric colorimeter). Cyanide determinations were made by the pyridine barbatoric acid method.

Acute Toxicity Tests

Three laboratories were involved in running the acute toxicity tests for this study. The Region I EPA Laboratory in Lexington, Massachusetts performed *Daphnia pulex* and fathead minnow (*Pimephales promelas*) 48-hour static acute toxicity tests on all effluent samples except the composite effluent sample collected at the Foxboro Company site. The DWPC, Technical Services Branch in Westborough, Massachusetts conducted Microtox 30-minute static acute tests on all samples except for the Foxboro Company composite effluent sample. This latter sample was analyzed by the University of Massachusetts Department of Civil Engineering (DCE) in Amherst, Massachusetts; fathead minnow and *Daphnia magna* 48-hour static acute tests and the Microtox 30-minute test were conducted on this sample. *D. magna* was substituted for *D. pulex* by the DCE due to a population crash in the *D. pulex* culture.

EPA and DCE used the methods outlined by Peltier (1978) for the fathead minnow and *Daphnia* tests. Microtox evaluations conducted by DWPC and DCE followed the methods described by the manufacturer (Beckman Instruments, Inc., 1982).

The log-concentration vs. percent survival method (Peltier, 1978) was used to estimate LC_{50}s. EC_{50}s estimated for Microtox tests are based on the percent light diminution of the photobacterium used in the test. The method used in estimating EC_{50}s was the one described by the manufacturer (Beckman Instruments, Inc., 1982).

Predictions of Instream Toxicity

Predictions of instream toxicity based on acute toxicity test results were made using the following relationship (from Malina 1984):

Equation 1: $Q_s = DV(F_d)$ where Q_s = stream flow in liters per second necessary to dilute effluent sufficiently so as not to have a toxic effect

DV = dilution volume

$$= \frac{100-LC_{50}(\%)}{LC_{50}(\%)} Qe$$

Q_e = wastewater flow in liters per second

F_d = reciprocal of application factor (used to protect for possible chronic toxicity, e.g., if the application factor is 0.1, $F_d = 10$)

Flow records of each industry undergoing evaluation were supplied by the wastewater operators at each plant. The average flow per hour of discharge for a two-week period preceding each macroinvertebrate collection date was used to calculate Q_e (see above). LC_{50}'s and EC_{50}'s used in the calculation of Q_s were taken from results of acute toxicity tests run on full cycle of operation composite effluent samples (samples A-D from above).

Predictions of in-stream toxic effects were made for each of the sites. Six values of Q_s were calculated for each site: one for each toxicity test using an application factor of 0.1, and one for each test using no application factor. Values of Q_s were then compared to two Q_r values: one for each set of flow conditions encountered at times of macroinvertebrate sampling. In those situations where $Q_s:Q_r$ exceeded a value of 1.0, a prediction of "toxic effects" was made; where $Q_s:Q_r$ was less than 1.0, a prediction of "no toxic effects" was made. These results were than compared with macroinvertebrate analyses to evaluate the effectiveness of each test in predicting community changes.

Chemical evaluations of the same samples used in calculations of Q_s (i.e., samples A-D) were also used to predict toxic effects on receiving waters. These predictions, like those based on acute toxicity tests, were compared with results of macroinvertebrate community analyses.

The following relationship was utilized for these predictions:

Equation 2: $$T = \sum_{i=1}^{x} \frac{Qe \cdot Ci/(Qe + Qr)}{W_i}$$

where: T = toxic units of a particular effluent sample

C_i = concentration of chemical i (in mg/l) found in sample

x = the number of chemical components being evaluated

W_i = EPA Ambient Water Quality criterion (EPA, 1980) for chemical i (in mg/l) using water hardness values as specified below

Q_e = as above (in liters per second)

Q_r = flow of receiving water in liters per second

Toxic effects of each permitted chemical component are assumed to be additive and an effluent with a $T > 1.0$ would be considered to have toxic effects on the aquatic community in the receiving water.

Two sets of toxic units were computed for each site: one set utilizing "24-hour average" criteria for W_i and the other using "maximum daily" criteria for W_i. In those instances where water hardness values were needed to calculate a criterion, they were based on the most recent DWPC Lakes Report (Commonwealth of Massachusetts, DWPC, 1981a; 1981b; 1982; and 1984) for the river basin corresponding to each site. An unweighted mean value for water hardness was calculated for each site from the total of all reported water hardness values from inlets and outlets of lakes and ponds evaluated in each report. The following hardness values (in mg/l equivalent $CaCO_3$) were used in calculations of criteria: Whiting & Davis, Inc. - 61; Foxboro Company - 26; Columbia Mfg. Company - 15; Zero Corporation - 20.

RESULTS AND DISCUSSION

Habitat Analyses

Results of dissolved oxygen (D.O.), temperature, pH and current velocity determinations at macroinvertebrate sampling stations are listed in Table 3. Sampling dates for these parameters coincided with dates of macroinvertebrate collections.

Data for these parameters were essentially similar at upstream and downstream stations on any given date except in the following cases: D.O. at the Foxboro Company and Columbia Mfg. Company sites; temperature and pH at the Columbia Mfg. Company site.

Differences in D.O. between sampling stations at the Foxboro Company site are small (0.2 mg/l) and are within the range of natural variability in sampling. Differences in D.O. at the Columbia Mfg. Company site on July 14 are also indistinguishable from those due to natural sampling variability. However, those in the August 5 sample at Columbia Mfg. Company are somewhat greater (7.7:8.4)* and are probably due to other causes. The distance between upstream and downstream sampling stations (approximately 1 km) was greater at the Columbia site than at any of the other sites. There were no riffle areas in between the two stations and the stream was slow moving with sections of moss covered cobble and submergent vegetation. Increases in dissolved oxygen between the two stations may have been due to photosynthesis. This section of the river was fairly wide and exposed to considerable solar radiation; temperature increases from upstream to downstream stations were probably a result of this exposure rather than the Columbia Mfg. Company effluent which was not heated.

Differences in pH between sampling stations at Columbia Mfg. Company site are not considered to be significant due to the low precision of the Hach wide-range pH test kit that was used in these determinations.

Current velocities at upstream and downstream sampling locations at each site were considered to be essentially similar on dates when they were measured.

Chemical Data

Table 4a shows the concentration of chemical components of composite effluent samples used in predictions of instream toxicity. Chemical analysis of additional effluent samples was also conducted; results of these analyses are listed in Table 4b.

Wastewater and receiving water flow data are reported in Table 5. Wastewater flow values in this table represent the average flow over

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* Ratios are recorded as upstream:downstream values throughout the remainder of this report.

Table 3. Results of physical and chemical macrohabitat analyses of macroinvertebrate sampling stations upstream (up) and downstream (dn) of wastewater discharge sites in 1982.

		Whiting & Davis, Inc.		Foxboro Company		Columbia Mfg. Company		Zero Corporation
Sampling Date:		7/2	9/24	6/30	8/4	7/14	8/5	7/8
Parameter								
Temperature (°C)	up	19	18	18	18	20	22	17
	dn	19	18	18	18	21	24	17
Dissolved Oxygen (mg/l)	up	7.0	7.2	5.3	4.0	7.8	7.7	8.9
	dn	7.0	7.2	5.1	4.2	8.0	8.4	8.9
Percent Oxygen Saturation	up	75	75	55	42	85	87	91
	dn	75	75	55	44	87	98	91
pH (standard logarithmic units)	up	7.0	6.7	7.3	7.0	7.3	7.5	6.5
	dn	7.0	6.7	7.3	7.0	7.5	7.5	6.5
Current Velocity (meters per second)	up	.40	.09	.27	.08	.33	.38	.34
	dn	.41	.11	.30	.09	.31	.42	.30

Table 4a. Concentrations (mg/l) of chemicals found in representative effluent samples collected from electrofinishing plants in 1982. Sample types described in text. ND = not detected.

	Whiting & Davis, Inc. A	Foxboro Company B	Columbia Mfg. Company C	Zero Corporation D
Date of Effluent Collection:	12/8	11/10	11/4	7/27
Parameter				
Aluminum	6.9	4.0	0.11	1.8
Cadmium	ND	--	ND	ND
Total Chromium	0.02	0.01	0.25	0.19
Hexavalent Chromium	--	--	ND	--
Total Copper	0.42	2.2	0.04	0.04
Amenable Cyanide	--	--	--	--
Total Cyanide	ND	--	--	--
Lead	ND	0.3	0.1	0.07
Nickel	0.25	ND	1.5	ND
Silver	0.05	ND	--	ND
Zinc	0.11	0.04	1.3	0.02

Table 4b. Concentrations (mg/l) of chemicals found in effluent samples taken at each of three sites in 1982. Sample types described in text.

	Whiting & Davis, Inc.	Foxboro Company		Zero Manufacturing
	E	F	G	H
Date of Effluent Collection:	9/8	7/14	7/14	8/3
Parameter				
Aluminum	1.5	8.2	4.9	0.1
Cadmium	--	ND	ND	ND
Total Chromium	0.02	ND	ND	0.25
Hexavalent Chromium	ND	ND	ND	ND
Total Copper	0.6	4.3	2.2	0.03
Amenable Cyanide	0.01	--	--	--
Total Cyanide	0.01	--	--	--
Lead	--	0.68	0.36	ND
Nickel	0.53	0.4	0.1	0.64
Silver	0.13	ND	ND	ND
Zinc	0.25	0.03	ND	0.10

Table 5. Wastewater and receiving water flow data for all sites (in liters per second). All data are from 1982.

	Whiting & Davis, Inc.		Foxboro Company		Columbia Mfg. Co.		Zero Corp.
Date:	7/2	9/24	6/30	8/4	7/14	8/5	7/8
Flow of receiving water upstream of discharge	97.7	19.3	362.8	28.9	1124.0	830.0	507.5
Wastewater flow	6.2	5.6	3.7	3.1	18.0	17.7	0.48

times of discharge for a two week period prior to each macroinvertebrate sampling date. Receiving water flows were measured on dates listed in this table and correspond to dates of macroinvertebrate collections.

Calculated instream Toxic Units based on Equation 2 are listed in Tables 6a and 6b. "24-hour average" EPA Ambient Water Quality Criteria (EPA, 1980) are used for W_i in equation 2 for Table 6a; "daily maximum allowable" EPA Ambient Water Quality Criteria (EPA, 1980) are used for the same variable in Table 6b. Values for Q_e and Q_r used in calculations of Toxic Units in Tables 6a and 6b were taken from Table 5. Toxic Unit values of 1.0 or greater are in excess of the criterion established for that component.

Toxic Units of 1.0 or greater were found at three sites: Whiting & Davis, Inc.; Foxboro Company; and Columbia Mfg. Company. At the Whiting & Davis, Inc. site under the July 2 flow conditions, two metals, copper and silver, would have exceeded the "24-hour average" criteria. Of these two, only silver would have also exceeded the "daily maximum allowable" concentration.

Under the flow conditions measured at the Whiting & Davis, Inc. site on September 24, (instream flow at that date was approximately 20% that of the previous date) copper and silver again would have exceeded the "24-hour average" criteria and both would also have exceeded the "maximum daily allowable" criteria.

At the Foxboro Company site, copper and lead would have exceeded the 24-hour average criteria under both sets of flow conditions but only copper would have been in excess of the "daily maximum" criterion.

Two substances, lead, and nickel, would have exceeded the "24-hour" criteria at the Columbia Mfg. Company site under both sets of flow conditions. In addition, zinc would have exceeded the "24-hour" criterion under the July 14 flow conditions. None of these would have exceeded the "maximum daily allowable" criteria, however.

Acute Toxicity Tests

Rank sensitivity* of the acute toxicity tests was surprisingly consistent over the seven effluents that were evaluated (see Tables 7a and 7b). For each of the six samples found to be toxic by at least one of the tests, the Daphnia sp. 48-hour tests were the most sensitive, the Beckman Instruments Co. Microtox 30-minute tests were of

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* Defined here as the rank ordering of toxic responses to a particular waste. This is determined from a comparison of the ratio of the reciprocals of LC_{50}s or EC_{50}s of a variety of tests on a particular effluent. For example, the relative sensitivities for the D. pulex, Microtox and fathead minnow tests on sample "F" in Table 7b would be: 1/21:1/28:1/36 = 1.7:1.18:1.0; their rank sensitivities would be in the same order.

Table 6a. Toxic Units (see equation 2) of composite effluent samples based on "24-hour average" EPA Ambient Water Quality Criteria (EPA, 1980). ND = not detected. (Criterion for silver is the same in this table and 6b.) Dilutions for these calculations based on flow characteristics for dates listed.

	Whiting & Davis, Inc.		Foxboro Company		Columbia Mfg. Co.		Zero Corp.
Date:	7/2/82	9/24/82	6/30/82	8/4/82	7/14/82	8/5/82	7/8/82
Chemical							
Cadmium	ND	ND	--	--	ND	ND	ND
Chromium (Hexavalent)	--	--	--	--	ND	ND	--
Copper	4.48	16.9	3.97	38.06	0.11	0.15	<0.01
Cyanide	ND	ND	--	--	--	--	--
Lead	ND	ND	18.93	181.64	35.8	47.45	0.76
Nickel	0.23	0.86	ND	ND	1.04	1.39	ND
Silver	1.7	6.5	ND	ND	--	--	ND
Zinc	0.13	0.48	<0.01	0.08	1.21	0.58	<0.01
Total Toxic Units:	6.54	24.74	22.9	219.8	38.16	49.57	0.76

Table 6b. Toxic Units (see Table 6a) of composite effluent samples based on "daily maximum allowable" EPA Ambient Water Quality Criteria (EPA, 1980). ND = not detected.

	Whiting & Davis, Inc.		Foxboro Company		Columbia Mfg. Co.		Zero Corp.
Date:	7/2/82	9/24/82	6/30/82	8/4/82	7/14/82	8/5/82	7/8/82
Chemical							
Cadmium	ND	ND	--	--	ND	ND	ND
Chromium (Hexavalent)	--	--	--	--	ND	ND	--
Copper	1.8	6.8	1.09	10.53	0.17	0.22	<0.01
Cyanide	ND	ND	--	--	--	--	--
Lead	ND	ND	0.09	0.88	0.09	0.12	<0.01
Nickel	0.01	0.04	ND	ND	0.05	0.07	ND
Silver	1.7	6.5	ND	ND	--	--	ND
Zinc	0.03	0.11	<0.01	0.04	0.31	0.41	<0.01
Total Toxic Units:	3.54	13.45	1.18	11.45	0.62	0.82	<0.01

Table 7a. Results of static acute toxicity tests on composite effluent samples used for instream toxicity calculations. Values are reported as percent effluent yielding 48-hour LC_{50}s for *Daphnia* sp. and fathead minnows, and 30-minute EC_{50}s for Microtox. *Daphnia magna* was used in the Foxboro test; all other daphnid tests were run with *D. pulex*. NT refers to cases in which toxicity to test organisms was insufficient for the generation of an EC- or LC_{50}. See text for description of sample types.

	Whiting & Davis, Inc.	Foxboro Company	Columbia Mfg. Co.	Zero Corp.
Collection Date:	12/8/82	11/10/82	11/14/82	7/27/82
Sample Code:	A	B	C	D
Test				
Fathead Minnow	100	NT	NT	NT
Microtox	6.8	40	NT	27
Daphnia sp.	5.7	7.5	NT	9.3

Table 7b. Results of static acute toxicity tests on effluent samples taken in addtion to those used for instream toxicity calculations. Notation is the same as that in Table 7a with the exception that *Daphnia pulex* was used exclusively in the daphnid tests. See text for a description of sample types.

	Whiting & Davis, Inc.	Foxboro Company		Columbia Mfg. Co.
Collection Date:	9/7	7/14	7/14	8/3
Sample Code:	E	F	G	H
Test				
Fathead Minnow	40	36	45	NT
Microtox	13	28	16	NT
Daphnia pulex	2.4	21	15	NT

intermediate sensitivity and the fathead minnow 48-hour tests were the least sensitive.

There was a wide degree of variation in LC_{50}s and EC_{50}s among the three tests. For example, the range in these data for sample "F" (Table 7b) was only 15 units (the LC_{50} for the fathead minnow was at 36% effluent and the LC_{50} for *D. pulex* was at 21% effluent; the EC_{50} for Microtox was intermediate between the other tests). In comparison there was a range of 94.3 units in the effluent concentration yielding LC_{50}s for the *Daphnia* and fathead tests run on sample "A" (100% effluent for fatheads and 5.7% for *D. pulex*).

In comparisons of toxic:non-toxic responses of these tests the *Daphnia pulex* (*Daphnia magna* in sample "B") and the Microtox tests exhibited the highest degree of positive correlation. In all seven cases where they were run concurrently, *D. pulex* and Microtox tests both registered the same response (i.e., toxic/non-toxic). For sample "B" where *D. magna* was used, both this and the Microtox test were in agreement regarding toxicity. In contrast with these results, the *D. pulex* test and the fathead minnow test registered similar responses in six out of seven cases; the Microtox and fathead minnow tests registered similar responses in only six of eight cases. For the one effluent in which *D. magna* was used this test was not in agreement with the fathead minnow test regarding toxicity. In each of the cases where there was disagreement between tests, the fathead minnow test registered a nontoxic response while the others registered a toxic response.

The effluent samples yielding the greatest degree of divergence among the three tests in toxic:non-toxic responses were the composite effluent samples (Table 7a). In three out of the four sets of tests on these samples the fathead minnow test registered no toxicity; in the fourth test (sample "A") toxicity to fatheads was barely sufficient for the development of an LC_{50} (the LC_{50} was at 100% effluent). In contrast, the *D. pulex* test registered a toxic response in two of the three composite samples tested, *D. magna* yielded a toxic response in the one instance where it was used and the Microtox test registered a toxic response to three of the four samples tested.

Samples taken in addition to those used for predictions of instream toxicity (see Table 7b) were used as a rough check on the consistency of each effluent's toxicity to the organisms tested. At the Whiting & Davis, Inc. site effluent toxicity to Microtox and *Daphnia* showed very little change (cf. samples A and E, Tables 7a and 7b). Toxicity to fathead minnows, however, was quite different between these two samples. A similar situation was evident in the Foxboro Company samples (cf. sample B and samples F and G). Toxicity to *Daphnia* sp. and Microtox was comparable among all three samples but toxicity to fatheads was quite different. The two sets of data (samples C and H in these tables) for the Columbia Mfg. Company effluent are similar. Additional effluent samples were not collected at the Zero Corporation.

Macroinvertebrates

Data sets for each of the macroinvertebrate collections made at the four sites evaluated in this study can be found in Appendices 1-4. Numbers of individuals found in separate taxonomic groups are reported for each of the six Surber samples collected (three upstream and three downstream) during each sampling event at a particular site.

Figures 2A and 2B are a compilation of all community indices calculated for macroinvertebrate data sets. Table 8 is a summary of tests for differences between Shannon Weaver H' calculated for upstream and downstream data sets at each site.

Whiting & Davis, Inc.:

Data for the chironomid portion from one of the three downstream Surber samples are not available for the July 2, Whiting & Davis, Inc. sample collection (see Appendix 1a). For this reason, quantitative comparisons between upstream and downstream macroinvertebrate data are not justified and a qualitative evaluation of these collections was made to determine if there was an impact due to the discharge.

There is a high degree of similarity between upstream and downstream chironomid portions of the July 2 data set (see Appendix 1a): relative abundances of major chironomid taxa are quite similar. In both upstream and downstream collections, the two taxa encountered most frequently are the "other *Cricotopus*" group and *Cricotopus bicinctus*. In addition to these two taxa, there are five other groups that are well represented (>7 individuals/taxon) in samples taken from both upstream and downstream sampling stations.

Although there are differences in the distribution of rare (1 or 2 individuals) groups between collections for the two sampling stations, an evaluation of these data is not justified due to the difference in the number of chironomid samples analyzed for each station.

As no major differences were found between the two chironomid sample collections in the July 2 data set, chironomids were judged not to have been affected by the Whiting & Davis, Inc. effluent.

Frequency distributions of individuals among non-chironomid taxa were quite different at upstream and downstream stations on this date. Tubificid worms (95:0) were a major component of the upstream community and are quite equally distributed among all three samples taken at that station. They are completely absent from the downstream samples, however. *Asellus communis*, also a major component with fairly even distribution in the upstream data set, is much less abundant (30:6) in the downstream samples.

Another difference between data sets for this collection occurs in the Mollusca. There are four taxa of mollusca in the upstream samples and none in the downstream samples. Three of these are rare groups but

Figure 2A

Community indices calculated for macroinvertebrate samples taken upstream (U) ▨ and downstream (D) ░ of two electrofinishing wastewater discharges.

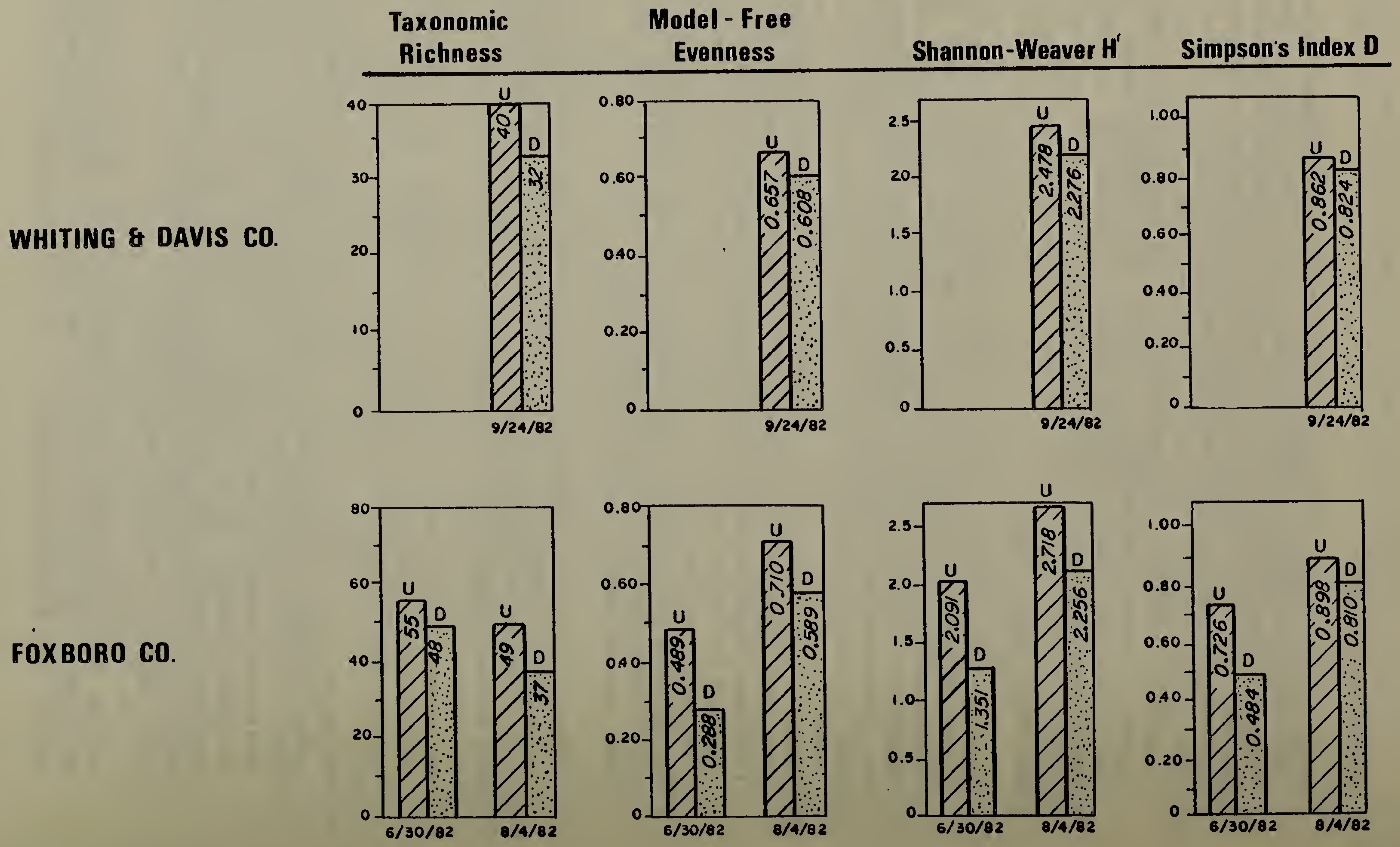

Figure 2B

Community indices calculated for macroinvertebrate samples taken upstream (U) ▨ and downstream (D) ░ of two electrofinishing wastewater discharges.

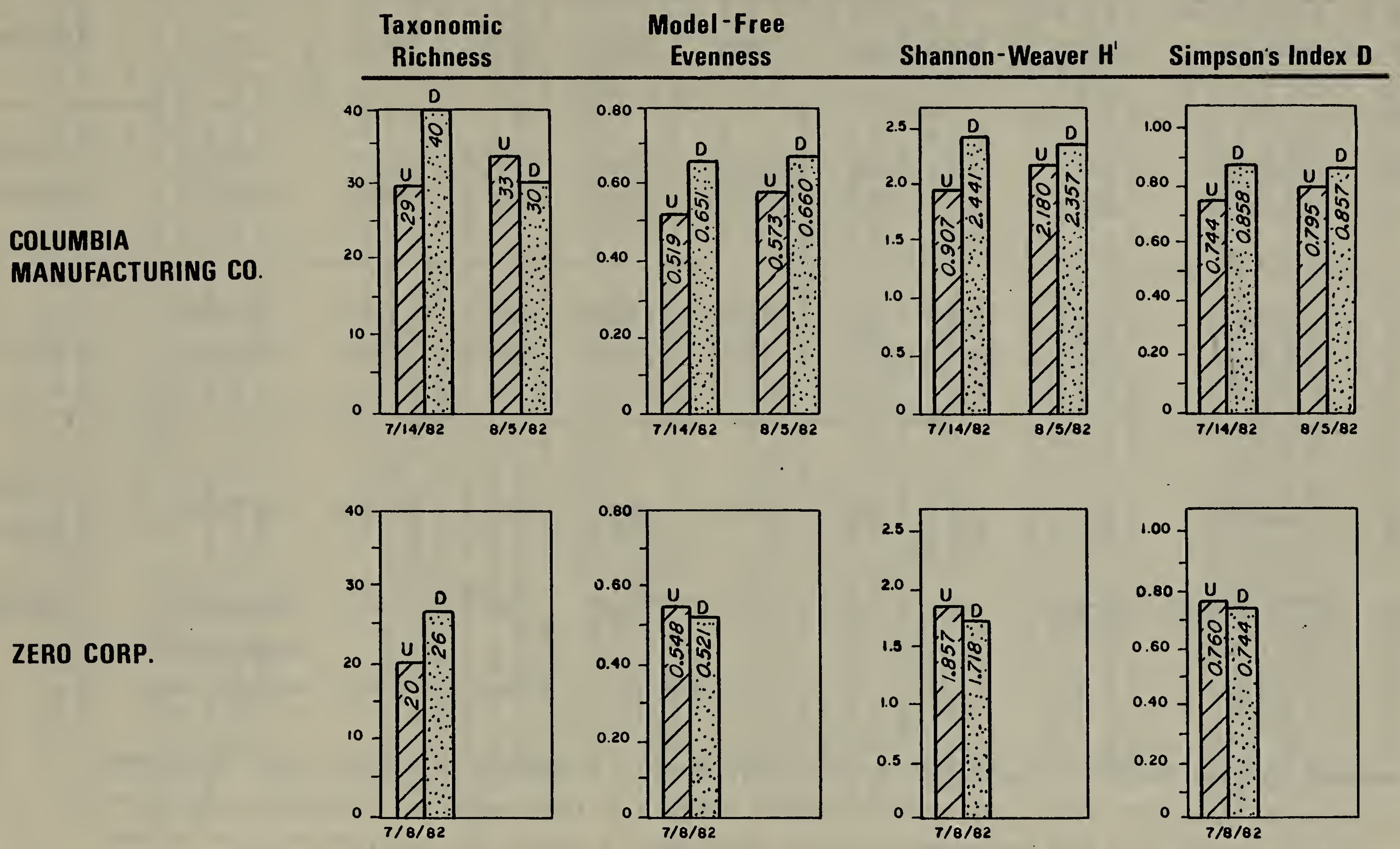

Table 8. Summary of tests for differences between Shannon Weaver H' calculated from composited macroinvertebrate samples collected upstream (up) versus H' from those collected downstream (dn) of electrofinishing wastewater discharges. An alpha level of 0.05 was used in a two-tailed t-test (see text) of the null hypothesis. df = degrees of freedom; p = probability level of incorrectly rejecting the null hypothesis.

Industry	Date of Macro-invertebrate collection	Shannon-Weaver H' up	Shannon-Weaver H' dn	Variance of H' up	Variance of H' dn	df	t	$t_{.05,\ df}$	$Ho: H'_{up} = H'_{dn}$	$P<$
Whiting & Davis Co.	9/24/82	2.4778	2.2755	0.0031	0.0094	374	1.993	1.960	rejected	0.05
Foxboro Co.	6/30/82	2.0906	1.3507	0.0016	0.0023	2829	11.850	1.960	rejected	0.001
	8/4/82	2.7177	2.2560	0.0013	0.0022	1817	7.804	1.960	rejected	0.001
Columbia Mfg. Co.	7/14/82	1.9067	2.4405	0.0043	0.0034	959	21.7	1.960	rejected	0.001
	8/5/82	2.1801	2.3565	0.0038	0.0028	1005	2.171	1.960	rejected	0.05
Zero Corp.	7/8/82	1.8565	1.7183	0.0077	0.0057	462	1.19	1.960	not rejected	--

the fourth (Gyraulus sp.) was found in all three of the upstream samples.

There are both fewer numbers (156:23) and fewer taxa (14:8) in the non-chironomid portions of the downstream data set when compared with the upstream portions. The two parameters are usually related: the probability of encountering more taxa increases with the sample size. However, a decrease in either is usually considered to be an indication of stress.

Based on the decrease in relative abundances of certain taxa from upstream to downstream sample collections, it was determined that negative impacts to the macroinvertebrate community occurred at Whiting & Davis, Inc. prior to July 2, 1982, due to the effluent discharge at that site, but they were not extensive.

On the second sampling date (September 24) at Whiting & Davis, Inc, there were consistent differences between stations in all community index values (see Figure 2 and Table 8). Taxonomic richness of the downstream data set (40:32) was 20% lower than for the upstream collection; Shannon Weaver H' was significantly lower ($p = 0.05$) for the downstream collection and Model-Free Evenness and Simpson's D were also lower in the downstream collection. The reduction in taxonomic richness in the downstream data set is probably in part a function of the difference in the total number of individuals (564:215) found in each collection. However, as was stated above, these are both considered to be indications of stress.

The major differences in the components of the macroinvertebrate collections for this date were as follows: Lumbriculus sp. (30:0), Asellus communis (166:29), Stenonema sp. (14:1), Ephemerellidae (13:0), Micropsectra type 1 (80:4) and Micropsectra type 2 (14:1).

The consistency in the differences between community indices of upstream and downstream collections, the differences between these collections in the better represented taxonomic groups and the drop in total number of individuals in downstream samples were considered sufficient to determine that the downstream macroinvertebrate community was stressed in comparison to the upstream community at the Whiting & Davis, Inc. site prior to September 24, 1982. Again, however these differences were not considered to be extensive.

Foxboro Company:

Consistent differences between upstream and downstream macroinvertebrate collections were most evident at this site: all community index values (see Table 8) were higher in upstream collections than in downstream collections for both sampling dates. There were also notable differences between the two sites in the relative distribution of individuals among the major taxonomic groups.

Although there was only a 12.7% decrease in Taxonomic Richness in the downstream collection (55:48) in the June 30 sample, there was a substantial drop in Model-Free Evenness (0.489:0.288). This change is primarily due to the fact that in the downstream sample one taxon (the Cheumatopsyche) accounts for 71% of the total number of individuals found across all taxa on that date. Although this same group also holds the greatest percentage of individuals found across all taxa in the upstream sample, it accounts for only 50% of the total number of individuals found in that collection. Total abundance of individuals in each collection did not differ drastically (1646:1386).

Shannon Weaver H' for the upstream collection was significantly higher (p<.001) than for the downstream collection (see Table 8). The difference in Simpson's index between the two sample collections was greater on this date than for all other sample collections evaluated in this study, with the upstream collection exhibiting the higher index value.

The most notable differences in the numbers of individuals found in the various taxa at the two sites on this date were: *Asellus communis* (142:18), Copepods (22:2), *Stenelmis* sp. 1 (53:8), *Hydropsyche* sp. (0:31), *Chironomus* sp. (34:3), *Cladotanytarsus* sp. (78:14), *Helisoma anceps* (24:3) *Helisoma trivolvis* (27:2) and *Sphaerium* sp. (10:0).

For the second collection taken at this site (August 4) the drop in Taxonomic Richness (24.5%) between the upstream and downstream samples was about twice that for the first sampling date. As there was not a large difference between sites in total abundance (1179:907) the drop in richness is important. The difference in evenness values (0.710:0.589) between the two data sets was small, however.

Shannon Weaver H' was significantly higher (p<.001) for the upstream data set than for the downstream data set (see Table 8). The degree of difference in Simpson's index was not as great as on the first date, but was still notable (0.8983:0.8098).

Major changes in the better represented components of the collections taken on this date were found in the following taxonomic groups: *Hydra* sp. (24:8), *Nais communis* (5:81), *Lumbriculidae* (111:0), *Asellus communis* (166:4), *Stenelmis* sp. (108:28), *Hydropsyche* sp. (2:68) several species of chironomids, *Helisoma trivolvis* (38:4) and *Sphaerium* sp. (22:0).

Based on an evaluation of the factors listed below, it was determined that negative impacts to the macroinvertebrate community occurred at the Foxboro Company site as a result of that facility's wastewater discharge:

a) the magnitude of the decrease in community index values from upstream to downstream data sets;

b) the consistency of these differences across all indices; and

c) the difference in the numbers of individuals found in the better represented taxonomic groups from the two data sets.

Columbia Manufacturing Company:

For the most part, samples taken at the Columbia Mfg. Company site exhibited trends in community structure that were the reverse of those found at the Foxboro Company and Whiting & Davis, Inc. sites. On the first date all index values (Figure 2) were higher for the downstream macroinvertebrate collection than they were for the upstream collection. Taxonomic Richness in the upstream collection was 28% lower (29:40) than in the downstream collection; Model-Free Evenness (0.519:0.651) and Simpson's D were also quite different; Shannon Weaver H' of the downstream collection was significantly higher (p <.001) than that of the upstream collection on this date (Table 8).

Differences between the collections in better represented taxonomic groups were not as great as might be expected from a review of the community indices. The only notable differences were the following: *Baetis* sp. (16:84), *Epeorus* sp. (2:15), *Cricotopus bicinctus* (9:39). Although the number of individuals taken at the downstream location was only slightly greater than the number taken upstream (471:511) the number of rare taxa was much greater in the downstream collection (17:24). This accounts for most of the difference in the total number of taxa found in the two collections on this first collection date.

Although the community index values suggest major differences in community structure, the differences in macroinvertebrate collections were primarily restricted to those groups that had only minor representation in the collections. Differences were considered to be present, but only marginally so, with the upstream community exhibiting signs of stress when compared with the downstream community.

In the second set of collections (August 5, 1982) Taxonomic Richness was slightly greater for the upstream collection (33:30) while other indices were greater for the downstream collection. Shannon Weaver H' of the downstream data set was significantly higher (p = 0.05) than that of the upstream data set (Table 8). Differences between collections for major taxonomic groups were few: *Stenonema* sp. (17:2), *Cardiocladius obscurus* group (2:38), and *Simulium* sp. (4:39).

Although there were only small differences between sites in the major taxonomic groups, index values were consistently higher at the downstream sampling station. As a result, no implications of negative impact due to the effluent discharge was inferred at this site.

Differences between upstream and downstream data sets at these sites may be related to the agricultural activities in open farmland just north of the upstream site (see Figure 1c). Dipel (which contains *Bacillus thuringiensis* H-strain) and Thiodan (Endosulfan) were applied to these fields over the summer of 1982. It is possible that during periods of wet weather, runoff from these areas may have entered the Little River and adversely affected the macroinvertebrate community at the upstream station. Analysis of instream samples for these constituents was not conducted, however, and implications regarding a connection between the application of these chemicals and instream effects on macroinvertebrates cannot be substantiated.

Zero Corporation:

The analysis of only one set of macroinvertebrate collections (those taken on July 8, 1982) will be presented here (see Appendix 4a). Taxonomic richness (Figure 2) for the July 8 collections was higher at the downstream location (20:26); however, the other indices were all lower for the downstream collection. A test of the null hypothesis that H' for the two collections was the same was not rejected at the alpha = .05 level (Table 8).

There were notable differences in the distribution of individuals across major taxonomic groups: Baetis sp. (37:108) Pseudocloeon sp. (6:98), Glossosoma sp. (90:18), and Neophylax sp. (11:1). Note that there is an inconsistency in which collection exhibited higher representation in these groups.

Both upstream and downstream data sets had fairly low diversity values. The explanation for this is that in both data sets, a small percentage of the total number of taxa contained a high proportion of the total number of individuals. At the upstream location, three taxonomic groups (out of the 20 total) contained 76% of the total number of individuals in the collection; at the downstream location three groups (of the 26 total) contained 83% of the total number of individuals in the collection.

Upstream and downstream data sets collected at the Zero Corporation site are quite different. There are substantial dissimilarities between these two data sets in the relative proportions of individuals found among major taxa. However, neither collection was considered to exhibit any signs of stress in comparison to the other, for the following reasons:

a) there were inconsistancies in the community index values from upstream to downstream data sets;

b) there was no reduction in the number of major taxonomic groups from one data set to the next.

As a result of the above, the wastewater discharge from the Zero Corporation was not found to have a negative impact on the macroinvertebrate community found in the receiving stream.

Predicted vs. Observed Effects

Chemical Evaluations:

Chemical evaluations of wastewater samples, based on EPA Ambient Water Quality Criteria (EPA, 1980), were fairly successful in predicting whether or not a toxic effect to instream communities should be observed (cf. Table 6a and Table 9). For both the Whiting & Davis, Inc. and Foxboro Company sites, under both sets of flow conditions, "24-hour average" as well as "daily maximum" criteria were exceeded for at least one of the effluent components.

These results concurred with the results of the macroinvertebtate analyses. At the Columbia Mfg. Company site, however, "24-hour average" criteria were exceeded (see lead and nickel, Table 6a) but no impacts due to the discharge were found through macroinvertebrate community analyses. "Daily maximum allowable" criteria (Table 6b) would not have been exceeded at this site under flow conditions found on either date. In addition, the sum of all toxic units for chemical components of this effluent did not exceed a value of 1.0.

At the Zero Corporation site none of the components exceeded the Ambient Water Quality Criteria. Total Toxic Units at this site were less than 1.0 for both "24-hour average" and "daily maximum allowable" criteria.

Acute Toxicity Evaluations:

Comparisons of predicted and observed instream toxicity are listed in Table 9. Predictions of instream toxicity are based on ratios of Qs:Qr from Equation 1 (see Methods). Numerical values for the components of this equation were obtained as follows: Qs and Qr from Table 5; toxicity test results from Table 7a. Ratios of Qs:Qr greater than 1.0 theoretically predict toxic effects to some aquatic organisms. Results of macroinvertebrate community analyses have been presented above and are listed in Table 9.

Two sets of predictions are made: one using an application factor of 0.1 and one without an application factor.

In those situations where toxic effects to macroinvertebrates were not observed (at the Columbia Mfg. Company and Zero Corporation sites) predictions matched results observed in all cases.

Where impacts to macroinvertebrate communities were observed (at the Whiting & Davis, Inc. and Foxboro Company sites) predictions only matched results observed in certain cases. Predictions based on *Daphnia pulex* and Microtox tests concurred with results of instream analysis at the Whiting & Davis, Inc. site under both sets of flow conditions. The sensitivity of the two tests was not the same, however. Under the September 24 flow regime (very low instream flows - see Table 5) both the Microtox and *D. pulex* tests predicted instream toxic effects *without an application factor*. Under the July 2 flow conditions when raw test results (no application factor) were used only the *Daphnia* test predicted toxic effects. In contrast to these findings, *the fathead* minnow test failed to predict observed effects under either set of flow conditions.

At the Foxboro Company site, the fathead minnow test again was ineffective in predicting effects observed through macroinvertebrate community investigations. Microtox test predictions matched observed effects only under the August 4 flow conditions (much reduced compared with the June 30 flow - see Table 5). The *D. magna* assay was the only test of the three for which predictions of *instream* toxic effects

Table 9. Comparisons of predicted and observed instream toxic effects from electrofinishing wastewater discharges. Predictions are based on Equation 1 of text both with and without an application factor (AF) of 0.1 (see text).

Site	Date of macroinvertebrate sampling	Acute Toxicity Test	Predictions of toxic effects based on Qs:Qr	Predictions of toxic effects based on Qs(AF):Qr	Results of macroinvertebrate community analyses
Whiting & Davis Co.	7/2/82	Minnow	No Effects	No Effects	Marginal Toxic Effects
		Microtox	No Effects	Toxic	
		D. pulex	Toxic	Toxic	
	9/24/82	Minnow	No Effects	No Effects	Marginal Toxic Effects
		Microtox	Toxic	Toxic	
		D. pulex	Toxic	Toxic	
Foxboro Company	6/30/82	Minnow	No Effects	No Effects	Toxic Effects
		Microtox	No Effects	No Effects	
		D. magna	No Effects	Toxic	
	8/4/82	Minnow	No Effects	No Effects	Toxic Effects
		Microtox	No Effects	Toxic	
		D. magna	Toxic	Toxic	
Columbia Mfg. Co.	7/14/82	Minnow	No Effects	No Effects	No Toxic Effects
		Microtox	No Effects	No Effects	
		D. pulex	No Effects	No Effects	
	8/5/82	Minnow	No Effects	No Effects	No Toxic Effects
		Microtox	No Effects	No Effects	
		D. pulex	No Effects	No Effects	
Zero Corp.	7/8/82	Minnow	No Effects	No Effects	No Toxic Effects
		Microtox	No Effects	No Effects	
		D. pulex	No Effects	No Effects	

under both sets of flow conditions matched effects observed through macroinvertebrate community investigations.

For the August 4 data set at the Foxboro site, the Daphnia test matched observed effects both with and without an application factor; for the same date, the Microtox test predicted toxic effects when test results were used in conjunction with an application factor, but did not predict effects without an application factor. For the June 30 data set, where only the D. magna test predictions matched observed effects, use of an application factor was necessary for an accurate prediction of effects.

When predictions based on both chemical evaluations and acute toxicity tests are compared with observed effects at all four sites, a major anomaly becomes apparent. If we take the ratios of Qs:Qr for Daphnia and Microtox and assume that there is a positive correlation between degree of toxicity and increasing values of this ratio, then impacts observed at Whiting & Davis, Inc. should have been greater than those observed at Foxboro Company. This was not the case however: only marginal toxic effects were observed at Whiting & Davis, Inc. in comparison to those found at the Foxboro Company site.

One important factor not taken into account in these comparisons is the duration of each discharge. Whiting & Davis, Inc. had an 8-hour discharge while Foxboro Company had a 24-hour discharge. A 16-hour interval between exposures to the Whiting & Davis, Inc. effluent may have had the effect of providing a recovery period for certain components of the aquatic community, permitting a greater diversity of taxa to persist than would otherwise under a 24-hour discharge of the same toxicity.

This inconsistency indicates a potential problem in the interpretation of toxicity test results. Since toxicity is often a factor of both a) toxicant concentration and b) time of exposure, effluent criteria for toxic wastes should take both these factors into consideration. While differences in effluent duration have been accounted for in the EPA Ambient Water Quality Criteria (EPA 1980) (for single chemicals) by the inclusion of 24-hour criteria, methods for incorporating effluent duration into the interpretation of toxicity test results for industrial permit evaluations have yet to be suggested.

CONCLUSIONS

Based on the results of this study, the Daphnia pulex 48-hour static acute test would be the test of choice in evaluating potential impacts to lotic environments subject to electrofinishing wastes. For the seven effluents where it was used to evaluate toxicity, this test was either as sensitive as or more sensitive than the other tests. In addition, this and the D. magna test were found to be the best predictors of toxic effects to macroinvertebrate communities at the sites evaluated in this study.

The Microtox 30 minute static acute toxicity test was not as sensitive as the Daphnia tests for the samples evaluated in this study, but was always in agreement with the latter tests regarding whether or not a sample was toxic. The inferior sensitivity of this test in comparison with the Daphnia tests prohibited it from being as accurate a predictor of toxic effects to macroinvertebrate communities evaluated in this research but it was still superior to the fathead minnow test for the effluents evaluated in this research.

The fathead minnow 48-hour static acute toxicity test was the least sensitive of the tests in this study and failed to predict macroinvertebrate community changes due to effluent discharges when they were observed in receiving waters.

Chemical evaluations, based on the list of components in NPDES permits at each site and compared with EPA Ambient Water Quality Criteria (EPA, 1980) were good predictors of instream toxic effects where the latter were observed but also predicted toxic effects in one case where impacts were not observed.

ADDENDUM

Application factors for acute tests are often based on acute: chronic ratios. These tests are usually run in a laboratory under conditions of constant effluent concentrations unless on-site flow through methods are used. Unfortunately, the latter conditions do not mimic those met in the field where batch treatment and discharge or intermittent discharges of varying toxicity are more commonly encountered. Since the effects of each individual set of conditions on test organisms cannot be predicted, it is apparent that when permit limitations are based on results of toxicity tests, test conditions should parallel conditions encountered on-site as closely as possible.

There are two basic approaches to this problem: 1) alter the test to match the conditions in the field, e.g., run flow-through acute and chronic tests on-site and develop application factors from the results of these tests; or 2) change your field conditions to meet the assumptions of your test.

The state of Connecticut, in effect, has chosen the second alternative. In that state 24-hour flow equalization is being required of facilities applying for NPDES permits. The effects of this requirement on toxicity and its regulation are: a) in-stream toxic "shocks" due to batch discharges of new facilities will be ameliorated since the variance in toxic strength will be lessened; and b) application factors based on toxicity tests can be determined with greater confidence since conditions for tests used in permit evaluations and those encountered at the point of discharge will be nearly similar.

A toxicity-based permit at such a facility might involve the development of one or two acute:chronic values for the determination of an application factor. Monitoring would then be based on periodic acute tests which are much less costly than chronic tests. Over time, if acute:chronic ratios of particular effluent classes are found to fall within a certain range, permitting agents could develop application factors for those classes and monitor facilities falling in that class through periodic acute tests.

In the meantime, while there continue to be gross inconsistencies between laboratory and field conditions, it should be kept in mind that the choice of any one application factor for use with acute toxicity test data should be a conservative one.

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Appendix 1a. Taxonomic list for Whiting & Davis Inc., Plainville, MA., July 2, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Upstream	Downstream
NEMATODA (roundworms)	1	0	0	1	1	0	1	2
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Naididae	0	3	1	0	0	0	4	0
Tubificidae								
Limnodrilus hoffmeisteri	1	0	2	0	0	0	3	0
Immature w/o capilliform setae	35	34	26	0	0	0	95	0
Lumbriculida								
Lumbriculidae	1	0	1	1	1	0	2	2
ARTHROPODA								
Crustacea								
Isopoda (sow bugs)								
Asellidae								
Asellus communis	8	8	14	4	2	0	30	6
Insecta								
Ephemeroptera (mayflies)								
Baetidae								
Baetis sp.	0	0	0	0	1	0	0	1
Stenonema sp.	0	0	1	0	0	0	1	0
Coleoptera (beetles)								
Dytiscidae (predaceous diving beetles)								
Agabus sp.	0	0	0	0	0	1	0	1
Elmidae (riffle beetles)								
Stenelmis sp.	0	0	0	1	0	0	0	1
Trichoptera (caddisflies)								
Hydropsychidae								
Hydropsyche sp.	1	1	3	3	4	2	5	9
Diptera (true flies)								
Chironomidae (midges)								
Tanypodinae								
Natarsia type 1	1	0	0	--*	0	0	1	0
Thienemannimyia group	11	7	13	--	9	5	31	14
Chironominae								
Cryptochironomus fulvus group	0	0	1	--	2	1	1	3
Phaenopsectra sp.	14	7	18	--	6	3	39	9
Polypedilum sp.	0	0	1	--	0	1	1	1
Micropsectra sp.	3	7	16	--	2	15	26	17
Rheotanytarsus exiguus group	0	1	0	--	0	0	1	0

Appendix 1a (Continued)

Whiting & Davis Inc., July 2, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Orthocladiinae								
Cricotopus bicinctus	7	12	41	--	16	30	60	46
Cricotopus sylvestris group	2	0	0	--	0	0	2	0
Cricotopus tremulus group	2	6	5	--	24	8	13	32
Other *Cricotopus*	48	11	112	--	8	97	171	105
Eukiefferiella sp. I	0	0	0	--	0	1	0	1
Eukiefferiella claripennis group	0	3	4	--	3	5	7	8
Psectrocladius sp.	0	0	1	--	0	0	1	0
Synorthocladius sp.	0	0	1	--	0	0	1	0
Other Chironomidae	0	0	0	--	1	0	0	1
Simuliidae (black flies)	0	0	1	--	0	0	1	0
Empididae (dance flies)	0	0	1	--	0	1	1	1
MOLLUSCA								
Gastropoda (snails)								
Basommatophora								
Physidae								
Physella sp.	1	0	0	0	0	0	1	0
Planorbidae								
Gyraulus sp.	4	1	5	0	0	0	10	0
Ancylidae								
Ferrissia sp.	0	0	1	0	0	0	1	0
Pelecypoda (clams, mussels)								
Heterodonta								
Pisidiidae								
Musculium sp.	0	1	0	0	0	0	1	0
Total no. individuals:	140	102	269	10	80	170	511	260
Total no. taxa:							28	19

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* refers to a sample which was lost.

Appendix 1b. Taxonomic list for Whiting & Davis Inc., Plainville, MA., Sept. 24, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
PLATYHELMINTHES								
Turbellaria (flatworms)								
Tricladida	0	0	0	3	0	0	0	3
NEMATODA (roundworms)	0	0	0	1	1	0	0	2
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Tubificidae								
Limnodrilus hoffmeisteri	0	1	0	0	2	0	1	2
Immature w/o capilliform setae	21	5	35	1	14	5	61	20
Immature with capilliform setae	1	0	2	0	2	0	3	2
Lumbriculida								
Lumbriculidae								
Lumbriculus sp.	28	0	2	0	0	0	30	0
Hirudinea (leeches)								
Pharyngobdellida								
Erpobdellidae								
Erpobdella punctata	0	0	0	1	0	0	0	1
ARTHROPODA								
Crustacea								
Isopoda (sow bugs)								
Asellidae								
Asellus communis	40	61	65	4	18	7	166	29
Amphipoda (scuds, sideswimmers)								
Crangonycidae								
Crangonyx sp.	1	3	1	0	1	1	5	2
Insecta								
Ephemeroptera (mayflies)								
Baetidae								
Baetis sp.	0	1	0	0	0	0	1	0
Cloeon sp.	0	0	1	0	0	1	1	1
Pseudocloeon sp.	0	0	1	0	0	1	1	1
Heptageniidae								
Stenonema sp.	2	12	0	1	0	0	14	1
Leptophlebiidae								
Paraleptophlebia sp.	1	0	3	0	0	1	4	1
Ephemerellidae								
Ephemerella sp.	1	7	5	0	0	0	13	0
Caenidae								
Caenis sp.	0	0	2	0	0	0	2	0

Appendix 1b (Continued)

Whiting & Davis Inc., Sept. 24, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Odonata (dragonflies and damselflies)								
Calopterygidae								
Agrion sp.	0	0	0	1	0	0	0	1
Coenagrionidae								
Ischnura sp.	1	0	0	2	0	0	1	2
Coleoptera (bettles)								
Haliplidae (crawling water beetles)								
Peltodytes sp.	0	0	0	1	0	1	0	2
Dytiscidae (predaceous diving beetles)								
Colymbates/Rhantus	0	0	0	0	1	0	0	1
Hydroporus sp.	0	0	0	1	2	0	0	3
Megaloptera								
Sialidae (alderflies)								
Sialis sp.	0	0	1	0	0	0	1	0
Corydalidae (dobsonflies)								
Nigronia sp.	0	0	1	1	1	0	1	2
Trichoptera (caddisflies)								
Hydropsychidae								
Cheumatopsyche sp.	7	8	0	3	1	1	15	5
Hydropsyche sp.	1	2	0	0	0	0	3	0
Limnephilidae								
Hydatophylax sp.	1	0	0	0	0	0	1	0
Leptoceridae								
Mystacides sp.	12	11	9	7	15	56	32	78
Diptera (true-flies)								
Chironomidae (midges)								
Tanypodinae								
Natarsia type 1	0	1	0	0	0	0	1	0
Psectrotanypus sp.	0	0	1	0	0	0	1	0
Thienemannimyia group	31	26	4	5	9	14	61	28
Chironominae								
Cryptochironomus fulvus group	4	0	0	0	0	0	4	0
Phaenopsectra sp.	3	4	0	1	3	4	7	8
Polypedilum sp.	0	0	0	1	1	3	0	5
Tribelos sp.	0	0	0	0	2	0	0	2
Micropsectra type 1	41	25	14	1	0	3	80	4
Micropsectra type 2	7	5	2	1	0	0	14	1
Micropsectra type 3	0	2	0	0	0	0	2	0
Rheotanytarsus sp.	0	0	1	0	0	0	1	0
Zavrelia sp.	2	0	0	0	0	0	2	0
Orthocladiinae								
Cricotopus bicinctus group	3	0	1	2	1	0	4	3
Cricotopus tremulus group	1	0	0	0	0	0	1	0

Appendix 1b (Continued)

Whiting & Davis Inc., Sept. 24, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Other *Cricotopus*	0	1	1	1	0	0	2	1
Parakiefferiella sp.	0	0	0	0	1	0	0	1
Parametriocnemus sp.	0	2	0	0	0	0	2	0
Psectrocladius sp.	1	0	0	0	0	0	1	0
Synorthocladius sp.	2	4	1	1	0	0	7	1
Other Chironomidae	0	0	0	1	0	0	0	1
Empididae (dance flies)	1	1	1	0	0	0	3	0
MOLLUSCA								
Gastropoda (snails)								
Basommatophora								
Planorbidae								
Gyraulus sp.	2	0	0	0	0	0	2	0
Ancylidae	2	3	2	0	0	1	7	1
Pelecypoda (clams, mussels)								
Heterodonta								
Pisidiidae	2	4	0	0	0	0	6	0
Total no. individuals:	219	189	156	41	75	99	564	215
Total no. taxa:							40	32

Appendix 2a. Taxonomic list for Foxboro Co. (E. Bridgewater), June 30, 1982.

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
NEMATODA (roundworms)	0	1	0	0	0	0	1	0
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Naididae								
Nais communis	1	1	0	0	0	0	2	0
Nais variabilis	0	0	0	0	1	1	0	2
Pristina sp.	0	0	0	0	1	0	0	1
Stylaria sp.	0	0	0	0	1	0	0	1
Enchytraeidae	0	0	0	0	1	2	0	3
Tubificidae	0	5	1	0	0	0	6	0
Lumbriculida								
Lumbriculidae	0	1	1	0	3	1	2	4
ARTHROPODA								
Crustacea								
Isopoda (sow bugs)								
Asellidae								
Asellus communis	9	17	116	5	8	5	142	18
Amphipoda (scuds, sideswimmers)								
Gammaridae	0	0	1	0	0	0	1	0
Cladocera (water fleas)	1	0	0	0	0	0	1	0
Copepoda (copepods)	22	0	0	0	0	2	22	2
Insecta								
Odonata (dragonflies and damselflies)								
Libellulidae								
Sympetrum sp.	1	0	0	0	0	0	1	0
Hemiptera (true bugs)								
Corixidae (water boatmen)	0	0	0	0	0	1	0	1
Coleoptera (beetles)								
Haliplidae (crawling water beetles)								
Haliplus sp.	1	0	0	0	0	0	1	0
Peltodytes sp.	4	3	1	0	0	0	8	0
Dytiscidae (predaceous diving beetles)								
Agabus sp.	0	1	0	1	0	0	1	1
Hydaticus sp.	0	0	0	0	0	1	0	1
Hydroporus sp.	0	0	0	0	0	1	0	1
Hygrotus sp.	0	0	2	0	1	0	2	1
Laccophilus sp.	0	0	0	0	1	0	0	1
Gyrinidae (whirligigs)								
Dineutus sp.	1	1	1	2	0	0	3	2
Hydrophilidae (water scavenger beetles)								
Anacaena sp.	0	0	1	0	0	0	1	0
Enochrus sp.	0	0	0	0	1	1	0	2
Helophorus sp.	0	0	1	0	0	0	1	0
Hydrobius sp.	0	0	1	0	0	0	1	0

Appendix 2a (Continued)

Foxboro Co., June 30, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Other Hydrophilidae	1	0	0	0	0	0	1	0
Elmidae (riffle beetles)								
Ancyronyx sp.	1	0	0	0	0	0	1	0
Dubiraphia sp.	1	10	0	0	1	0	11	1
Stenelmis sp. 1	22	19	12	0	7	1	53	8
Megaloptera								
Sialidae (alderflies)								
Sialis sp.	1	1	0	0	0	0	2	0
Trichoptera (caddisflies)								
Hydropsychidae								
Cheumatopsyche sp.	381	310	136	216	397	370	827	983
Hydropsyche sp.	0	0	0	3	26	2	0	31
Diptera (true flies)								
Ceratopogonidae (biting midges)	0	0	1	0	2	0	1	2
Chironomidae (midges)								
Tanypodinae								
Ablabesmyia sp.	0	1	0	0	0	0	1	0
Natarsia type 1	1	0	0	1	0	0	1	1
Natarsia type 2	0	0	0	0	1	0	0	1
Thienemannimyia group	14	16	12	13	1	8	42	22
Chironominae								
Chironomus decorus/riparius group	0	1	1	0	0	4	2	4
Other *Chironomus*	25	8	1	1	1	1	34	3
Cryptochironomus fulvus group	4	1	0	0	0	0	5	0
Dicrotenpides neomodestus	1	0	0	1	0	0	1	1
Dicrotendipes nervosus type 1	0	0	1	0	0	2	1	2
Dicrotendipes nervosus type 2	0	0	0	0	3	0	0	3
Parachironomus abortivus	0	0	0	0	0	1	0	1
Phaenopsectra flavipes	6	3	0	2	0	6	9	8
Polypedilum convictum	1	0	1	1	2	0	2	3
Polypedilum fallax group	6	0	0	1	2	3	6	6
Polypedilum illinoense	0	1	1	0	0	0	2	0
Polypedilum scalaenum	1	0	0	0	0	8	1	8
Cladotanytarsus sp.	15	15	48	3	4	7	78	14
Micropsectra type 1	5	1	3	0	2	0	9	2
Micropsectra type 2	32	49	18	14	15	7	99	36
Micropsectra type 3	3	0	0	0	0	0	3	0
Micropsectra type 4	4	1	0	0	0	0	5	0

Appendix 2a (Continued)

Foxboro Co., June 30, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Diamesinae								
Potthastia longimanus	1	0	2	1	0	1	3	2
Orthocladiinae								
Cricotopus bicinctus	0	0	0	1	3	0	0	4
Cricotopus sylvestris group	0	0	1	0	0	0	1	0
Other *Cricotopus*	1	0	0	0	0	0	1	0
Orthocladius sp.	0	1	0	0	0	0	1	0
Tvetenia bavarica group	0	0	0	0	1	0	0	1
Simuliidae (black flies)								
Simulium sp.	1	0	54	24	18	1	55	43
Empididae (dance flies)	2	1	0	0	0	1	3	1
Sciomyzidae (marsh flies)								
Sepedon sp.	1	0	0	0	0	0	1	0
MOLLUSCA								
Gastropoda (snails)								
Basommatophora								
Physidae								
Physa sp.	14	13	84	26	73	40	111	139
Lymnaeidae								
Lymnaea sp.	0	0	2	0	3	1	2	4
Pseudosuccinea columella	0	0	0	1	0	0	0	1
Planorbidae								
Gyraulus sp.	0	1	13	1	0	0	14	1
Helisoma anceps	0	18	6	1	2	0	24	3
Helisoma trivolvis	14	3	10	1	1	0	27	2
Planorbula armigera	0	0	0	1	3	0	0	4
Pelecypoda (clams, mussels)								
Heterodonta								
Pisidiidae								
Sphaerium sp.	8	2	0	0	0	0	10	0
Total no. individuals:	607	506	533	321	586	479	1646	1386
Total no. taxa:							55	48

Appendix 2b. Taxonomic list for Foxboro Co., (E. Bridgewater), August 4, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
COELENTERATA								
Hydrozoa (hydroids)								
Athecata								
Hydridae								
Hydra sp.	0	1	23	0	0	0	24	0
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Naididae								
Nais communis	0	0	5	16	10	55	5	81
Nais variabilis	0	1	2	0	3	0	3	3
Pristina sp.	0	1	0	1	5	7	1	13
Enchytraeidae	0	0	0	0	0	4	0	4
Tubificidae								
Immature w/o capilliform setae	0	2	0	6	0	0	2	6
Lumbriculida								
Lumbriculidae	0	2	109	0	0	0	111	0
Hirudinea (leeches)	0	0	2	0	0	0	2	0
ARTHROPODA								
Crustacea								
Isopoda (sow bugs)								
Asellidae								
Asellus communis	25	11	130	3	1	0	166	4
Amphipoda (scuds, sideswimmers)								
Gammaridae	0	0	9	0	0	0	9	0
Insecta								
Ephemeroptera (may flies)								
Caenidae								
Caenis sp.	0	0	2	0	0	0	2	0
Coleoptera (beetles)								
Haliplidae (crawling water beetles)								
Peltodytes sp.	8	5	0	0	0	0	13	0
Gyrinidae (whirligigs)								
Dineutus sp.	2	3	2	1	2	2	7	5
Elmidae (riffle beetles)								
Dubiraphia sp.	3	1	0	0	1	0	4	1
Stenelmis sp.	48	41	19	1	6	21	108	28
Megaloptera								
Sialidae (alderflies)								
Sialis sp.	1	0	3	2	4	0	4	6

Appendix 2b (Continued)

Foxboro Co., August 4, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Trichoptera (caddisflies)								
Hydropsychidae								
Cheumatopsyche sp.	158	38	14	9	74	255	210	338
Hydropsyche sp.	0	2	0	0	2	66	2	68
Hydroptilidae								
Oxyethira sp.	2	3	0	0	0	0	5	0
Leptoceridae								
Mystacides sp.	1	0	0	1	0	0	1	1
Diptera (true flies)								
Tipulidae (crane flies)								
Tipula sp.	0	0	0	0	0	2	0	2
Ceratopogonidae (biting midges)	0	0	0	0	1	5	0	6
Chironomidae (midges)								
Tanypodinae								
Clinotanypus sp.	1	0	0	0	0	0	1	0
Guttipelopia sp.	0	1	0	0	0	0	1	0
Psectrotanypus sp.	1	0	0	0	0	0	1	0
Thienemannimyia group	101	46	49	61	53	50	196	164
Chironominae								
Chironomus sp.	0	0	10	1	0	0	10	1
Cryptochironomus fulvus group	2	1	1	0	2	0	4	2
Dicrotendipes nervosus type 1	0	0	0	1	0	0	0	1
Microtendipes caelum	0	0	0	1	0	0	0	1
Parachironomus abortivus	0	0	1	1	0	0	1	1
Phaenopsectra flavipes	2	1	0	3	1	1	3	5
Polypedilum convictum	1	3	0	0	0	0	4	0
Polypedilum fallax group	3	0	1	0	8	12	4	20
Polypedilum illinoense	5	1	2	1	4	2	8	7
Polypedilum scalaenum	7	7	1	0	0	0	15	0
Tribelos sp.	2	1	0	0	1	0	3	1
Cladotanytarsus sp.	17	11	15	12	8	3	43	23
Micropsectra type 1	8	5	5	0	0	0	18	0
Micropsectra type 2	17	3	4	1	4	1	24	6
Micropsectra type 3	1	1	1	0	0	0	3	0
Micropsectra type 4	1	1	0	0	0	0	2	0
Rheotanytarsus sp.	6	5	1	0	0	0	12	0
Orthocladiinae								
Cricotopus bicinctus	0	2	0	1	3	1	2	5
Cricotopus tremulus group	0	0	0	1	13	0	0	14
Nanocladius sp.	0	0	0	5	6	0	0	11
Parametrocnemus sp.	1	0	0	0	0	2	1	2
Rheocricotopus sp.	0	0	0	0	0	1	0	1
Thienemanniella sp.	0	0	0	0	1	0	0	1
Tvetenia bavarica group	0	1	0	0	0	0	1	0

Appendix 2b (Continued)

Foxboro Co., August 4, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Simuliidae (black flies)								
Simulium sp.	2	23	3	0	0	15	28	15
Empididae (dance flies)	8	3	9	4	6	35	20	45
MOLLUSCA								
Gastropoda (snails)								
Basommatophora								
Physidae								
Physa sp.	6	9	16	0	11	0	31	11
Planorbidae								
Helisoma anceps	0	1	0	0	0	0	1	0
Helisoma trivolvis	18	10	10	0	4	0	38	4
Planorbula armigera	0	0	2	0	0	0	2	0
Ancylidae								
Ferrissia sp.	0	1	0	0	0	0	1	0
Pelecypoda (clams, mussels)								
Heterodonta								
Pisidiidae								
Sphaerium sp.	10	6	6	0	0	0	22	0
Total no. individuals:	468	254	457	133	234	540	1179	907
Total no. taxa:							49	37

Appendix 3a. Taxonomic list for Columbia Manufacturing Co., Westfield, MA., July 14, 1982

Taxon	Number of individuals per sample Upstream			Downstream			Total Up-stream	Total Down-stream
ARTHROPODA								
Insecta								
Ephemeroptera (mayflies)								
Siphlonuridae								
Isonychia sp.	0	0	1	2	0	0	1	2
Baetidae								
Baetis sp.	0	8	8	53	15	16	16	84
Pseudocloeon sp.	0	0	1	1	9	0	1	10
Heptageniidae								
Epeorus sp.	0	2	0	12	0	3	2	15
Heptagenia sp.	0	1	0	0	0	0	1	0
Stenonema sp.	0	1	1	0	1	1	2	2
Stenacron sp.	1	0	0	0	0	0	1	0
Leptophlebiidae								
Paraleptophlebia sp.	1	0	0	1	0	0	1	1
Ephemerellidae								
Attenella sp.	0	0	0	0	1	0	0	1
Serratella sp.	8	6	4	0	11	8	18	19
Caenidae								
Caenis sp.	0	2	0	0	1	0	2	1
Plecoptera (stoneflies)								
Leuctridae								
Leuctra sp.	0	0	1	0	0	0	1	0
Perlidae								
Acroneuria sp.	0	0	0	0	2	0	0	2
Acroneuria georgiana	1	4	5	4	2	2	10	8
Coleoptera (beetles)								
Hydrophilidae (water scavenger beetles)								
Helophorus sp.	0	0	0	0	1	0	0	1
Psephenidae (water pennies)								
Psephenus herricki	1	0	0	0	1	0	1	1
Elmidae (riffle beetles)								
Ancyronyx variegata	1	0	0	0	0	0	1	0
Other Elmidae	0	0	0	0	1	1	0	2
Trichoptera (caddisflies)								
Philopotamidae								
Dolophilodes sp.	2	0	0	0	0	0	2	0
Chimarra sp.	0	0	0	1	1	0	0	2
Hydropsychidae								
Cheumatopsyche sp.	40	35	32	17	30	12	107	59
Hydropsyche sp.	85	68	55	49	61	40	208	150
Glossosomatidae								
Glossosoma sp.	0	0	0	1	0	0	0	1

Appendix 3a (Continued)

Columbia Manufacturing Co.,July 14, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Diptera (true flies)								
Tipulidae (crane flies)								
Antocha sp.	0	0	0	1	0	0	0	1
Chironomidae (midges)								
Tanypodinae								
Thienemannimyia group	0	2	1	2	1	1	3	4
Chironominae								
Phaenopsectra (prob. dyari)	1	0	0	0	0	0	1	0
Polypedilum convictum	3	8	2	3	2	1	13	6
Micropsectra type 1	2	0	7	1	2	2	9	5
Micropsectra type 2	0	2	0	0	0	0	2	0
Micropsectra type 4	1	0	0	0	0	0	1	0
Rheotanytarsus distinctissimus	0	0	0	0	1	0	0	1
Rheotanytarsus exiguus	6	14	6	4	7	6	26	17
Diamesinae	2	0	0	2	4	1	2	7
Orthocladiinae								
Cardiocladius obscurus	0	0	0	1	1	0	0	2
Cricotopus bicinctus	1	6	2	4	25	10	9	39
Cricotopus intersectus group	0	0	0	0	2	0	0	2
Cricotopus tremulus group	0	0	0	0	5	4	0	9
Cricotopus sp. 3	0	0	0	0	2	0	0	2
Eukiefferiella claripennis group	0	0	0	0	1	0	0	1
Orthocladius type 3	1	0	0	0	0	1	1	1
Orthocladius obumbratus	0	0	0	0	1	1	0	2
Parametrocnemus sp.	0	0	0	0	1	0	0	1
Rheocricotopus sp.	0	0	0	0	1	0	0	1
Synorthocladius sp.	0	0	0	0	0	1	0	1
Tvetenia bavarica group	0	0	0	0	1	0	0	1
Tvetenia discoloripes group	8	10	8	14	20	6	26	40
Simuliidae (black flies)								
Simulium sp.	0	0	3	6	0	0	3	6
Empididae (dance flies)	0	0	0	1	0	0	0	1
Total no. individuals:	165	169	137	180	214	117	471	511
Total no. taxa:							29	40

Appendix 3b. Taxonomic list for Columbia Manufacturing Co., Westfield, MA., August 5, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
NEMATODA (roundworms)	0	0	1	0	0	0	1	0
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Naididae								
Nais behningi	0	0	3	0	0	4	3	4
Nais communis	2	2	4	1	0	5	8	6
Slavina appendiculata	0	0	0	0	0	2	0	2
ARTHROPODA								
Insecta								
Ephemeroptera (mayflies)								
Siphlonuridae								
Isonychia sp.	4	7	4	0	0	6	15	6
Baetidae								
Baetis sp.	4	5	4	8	6	10	13	24
Pseudocloeon sp.	10	8	8	38	19	20	26	77
Heptageniidae								
Stenonema sp.	5	8	4	0	0	2	17	2
Ephemerellidae								
Serratella sp.	2	1	1	0	0	1	4	1
Tricorythidae								
Tricorythodes sp.	0	0	0	0	0	2	0	2
Plecoptera (stoneflies)								
Leuctridae								
Paraleuctra sp.	0	1	1	0	0	0	2	0
Perlidae								
Acroneuria sp.	0	1	0	0	0	0	1	0
Coleoptera (beetles)								
Gyrinidae (whirligigs)								
Dineutus sp.	1	0	1	0	0	0	2	0
Megaloptera								
Sialidae (alderflies)								
Sialis sp.	0	1	0	0	0	0	1	0
Corydalidae (dobsonflies)								
Nigronia sp.	1	0	0	0	0	0	1	0
Trichoptera (caddisflies)								
Philopotamidae								
Chimarra sp.	5	2	1	2	0	5	8	7
Hydropsychidae								
Cheumatopsyche sp.	19	16	14	4	5	4	49	13
Hydropsyche sp.	81	42	89	46	35	64	212	145
Glossosomatidae								
Glossosoma sp.	2	1	1	0	0	0	4	0

Appendix 3b (Continued)

Columbia Manufacturing Co., Westfield, MA., August 5, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Diptera (true flies)								
Tipulidae (crane flies)								
Antocha sp.	1	1	2	0	0	0	4	0
Other *Tipulidae*	0	0	0	1	0	0	0	1
Chironomidae (midges)								
Tanypodinae								
Thienemannimyia group	5	1	1	0	1	2	7	3
Chironominae								
Micropsectra type 2	1	3	1	0	0	0	5	0
Micropsectra type 3	0	0	0	0	0	1	0	1
Rheotanytarsus exiguus	27	12	43	14	12	27	82	53
Orthocladiinae								
Cardiocladius obscurus group	0	0	2	28	2	8	2	38
Cricotopus bicinctus	3	0	0	2	0	9	3	11
Cricotopus intersectus group	0	0	0	0	0	4	0	4
Cricotopus tremulus group	0	1	0	4	0	2	1	6
Cricotopus trifasciata	0	0	0	0	0	1	0	1
Other *Cricotopus*	0	0	1	1	0	0	0	1
Eukiefferiella claripennis group	0	0	1	1	0	0	1	1
Eukiefferiella pseudomontana group	1	0	0	2	0	1	1	3
Eukiefferiella similis group	1	1	1	0	0	0	3	0
Eukiefferiella gracei group	1	0	0	0	0	0	1	0
Nanocladius sp.	0	0	1	0	0	0	1	0
Orthocladius sp.	0	0	0	0	0	2	0	2
Orthocladius type 3	0	0	0	0	0	1	0	1
Orthocladius obumbratus	0	0	0	0	0	2	0	2
Tvetenia bavarica group	1	1	0	0	0	0	2	0
Tvetenia discoloripes group	15	4	21	12	3	18	40	33
Simuliidae (black flies)								
Simulium sp.	0	0	4	19	7	13	4	39
Empididae (dance flies)	0	2	1	0	1	1	3	2
Total no. individuals:	192	121	214	183	91	217	527	491
Total no. taxa:							33	30

Appendix 4. Taxonomic list for Zero Corporation, July 8, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
ANNELIDA								
Oligochaeta (aquatic earthworms)								
Haplotaxida								
Enchytraeidae	0	1	0	0	0	0	1	0
ARTHROPODA								
Insecta								
Ephemeroptera (mayflies)								
Baetidae								
Baetis sp.	7	14	16	39	17	52	37	108
Pseudocloeon sp.	3	1	2	17	18	63	6	98
Heptageniidae								
Epeorus sp.	0	0	0	1	0	0	0	1
Ephemerellidae								
Drunella sp.	0	0	0	0	1	0	0	1
Serratella sp.	0	0	0	1	0	0	0	1
Plecoptera (stoneflies)								
Leuctridae								
Leuctra sp.	0	1	0	0	0	0	1	0
Perlidae								
Acroneuria georgiana	0	0	0	1	0	1	0	2
Perlodidae								
Isoperla sp.	1	0	0	0	0	0	1	0
Coleoptera (beetles)								
Dytiscidae (predaceous diving beetles)								
Agabus sp.	0	0	0	1	0	0	0	1
Elmidae (riffle beetles)								
Promoresia elegans	1	1	0	0	0	0	2	0
Trichoptera (caddisflies)								
Philopotamidae								
Dolophilodes sp.	0	3	1	0	1	1	4	2
Hydropsychidae								
Cheumatopsyche sp.	2	1	1	2	0	0	4	2
Hydropsyche sp.	16	12	5	40	1	3	33	44
Rhyacophilidae								
Rhyacophila sp.	1	4	0	2	1	0	5	3
Glossosomatidae								
Glossosoma sp.	18	21	51	13	3	2	90	18
Brachycentridae	1	0	0	0	0	0	1	0
Limnephilidae								
Neophylax sp.	0	11	0	0	0	1	11	1

Appendix 4 (Continued)

Zero Corporation, July 8, 1982

Taxon	Number of individuals per sample						Total	
	Upstream			Downstream			Up-stream	Down-stream
Diptera (true flies)								
Chironomidae (midges)								
Podonominae	0	0	0	0	1	0	0	1
Chironominae								
Microtendipes caelum	0	0	0	0	1	0	0	1
Phaenopsectra (prob. dyari)	0	0	0	1	0	0	0	1
Micropsectra type 1	0	0	1	0	0	0	1	0
Micropsectra type 2	1	0	0	0	0	0	1	0
Rheotanytarsus sp.	1	0	0	1	0	0	1	1
Diamesinae	5	2	0	3	0	0	7	3
Orthocladiinae								
Cardiocladius obscurus group	0	0	0	0	0	1	0	1
Cricotorus bicinctus	0	0	0	2	1	1	0	4
Eukiefferiella claripennis group	0	0	0	0	0	3	0	3
Eukiefferiella brehmi group	0	0	0	1	0	0	0	1
Eukiefferiella pseudomontana group	0	0	0	0	1	0	0	1
Eukiefferiella similis group	0	0	0	1	0	0	0	1
Tvetenia bavarica group	0	1	1	0	0	0	2	0
Tvetenia discoloripes group	2	0	0	1	0	0	2	1
Empididae (dance flies)	0	1	0	1	0	0	1	1
Total no. individuals:	59	74	78	128	46	128	211	302
Total no. taxa:							20	26

Appendix 5. Community Indices

Abundance

Two abundance measures are used in this report: a) the sum total of individuals found in all taxonomic groups in a particular data set (termed "total numbers"); and b) the relative proportion of individuals found in different taxonomic categories (termed "relative abundance").

If a relationship between productivity and numbers of individuals can be established, increases from control to test sites in the total number of organisms found may be a result of increased nutrient availability. Decreases in this measure may be related to changes in nutrients and/or the influence of toxic stress. Changes in the relative abundance of major taxonomic groups may be related to habitat alterations between sites. When changes in the relative abundance of major groups are accompanied by a decrease in richness (see below) these may be due to either changes in nutrient availability and/or toxic stress.

Taxonomic Richness

This term refers to the number of different taxonomic groups in a particular sample. Comparisons of richness in this study are based on the assumption that physiological stress (defined as those instances under which environmental conditions such as temperature, oxygen concentration, pH, etc., exceed the tolerance limits of an individual) due to a toxic discharge can reduce the number of taxa originally inhabiting a certain area.

Richness of a sample collection is positively correlated with sampling effort. As area sampled, time spent sampling, and/or number of organisms collected are increased, the number of different taxa encountered also increase. For these reasons, comparisons should only be made between data sets for which sampling effort is similar or nearly so (see Hurlbert, 1971 for a thorough discussion of these ideas).

Evenness

This is a measure of the distribution of individual organisms over different taxonomic categories. Most evenness indices range from a value of zero to 1.0, with a completely uniform distribution yielding a value of 1.0.

Diversity indices (see below) compress richness and evenness into a single number. Information is lost in this process. In attempting to regain some of this information ecologists have used evenness or equitability ratios that are usually of the form: measured diversity/standard diversity, where the latter term is the maximum diversity of a community given a certain richness value. A basic problem with this approach is that the value of the ratio is dependent upon the particular characteristics of the diversity index. Thus, biases inherent to the index are incorporated into, and perhaps magnified by, the evenness ratio.

A new index formulated by Williams (1977), called Model-Free Evenness, circumvents the problem of model dependence by defining evenness in strictly geometric terms. The format of this index is presented below:

$$E = 1 - \sqrt{\frac{S\sum_{i=1}^{S}\Pi_i^{2} - 1}{S-1}}$$

where S = number of taxa
Π = the species frequency vector such that $\sum_{i=1}^{S}\Pi_i = 1$

Diversity Indices

Most diversity indices attempt to interdigitate and refine two components of community structure: richness and evenness. The two indices chosen in this study differ in their sensitivity to changes in certain aspects of these components. Whereas the Shannon Weaver index is more an expression of the overall evenness of the community, the Simpson's index expresses the relative degree of dominance of a few taxa in the community.

The Shannon Weaver H' is commonly used for two reasons: 1) it is simple in form; and 1) it has a known variance structure. Due to the latter attribute, a t-test for differences in H' between two data sets can be run. The form of the index used in this study and its variance structure were taken from Poole (1974) and are presented below.

$$H' = \left[-\sum_{i=1}^{S} pi\cdot\ln pi\right] - \frac{S-1}{2N}$$

where S = number of taxa
pi = the proportion of the total number of individuals consisting of the i^{th} taxon
N = total number of individuals

$$\text{Var. } H' = \frac{\sum_{i=1}^{S} pi\cdot\ln^{2} pi - \left[\sum_{i=1}^{S} pi\cdot\ln pi\right]^{2}}{N} + \frac{S-1}{2N^{2}}$$

The form of Simpson's Index (Simpson, 1949) used in this study was: D=1-C

where $C = \sum_{i=1}^{S}\frac{ni(ni-1)}{N(N-1)}$

and S = as above
ni = the number of individuals in the i^{th} species
N = as above

The term C is an approximation of the probability that two individuals drawn at random from a population of N individuals will belong to the same taxon. The higher this probability, the lower the "diversity" (as measured by this index) of the collection; hence D (equal to 1-C) is used as the index since this parameter will increase with the "diversity" of the sample.